ATMOSPHERIC TRACER STUDIES TO CHARACTERIZE THE TRANSPORT AND DISPERSION OF POLLUTANTS IN THE CALIFORNIA DELTA REGION

EXECUTIVE SUMMARY

Contract No. ARB-A5-065-87

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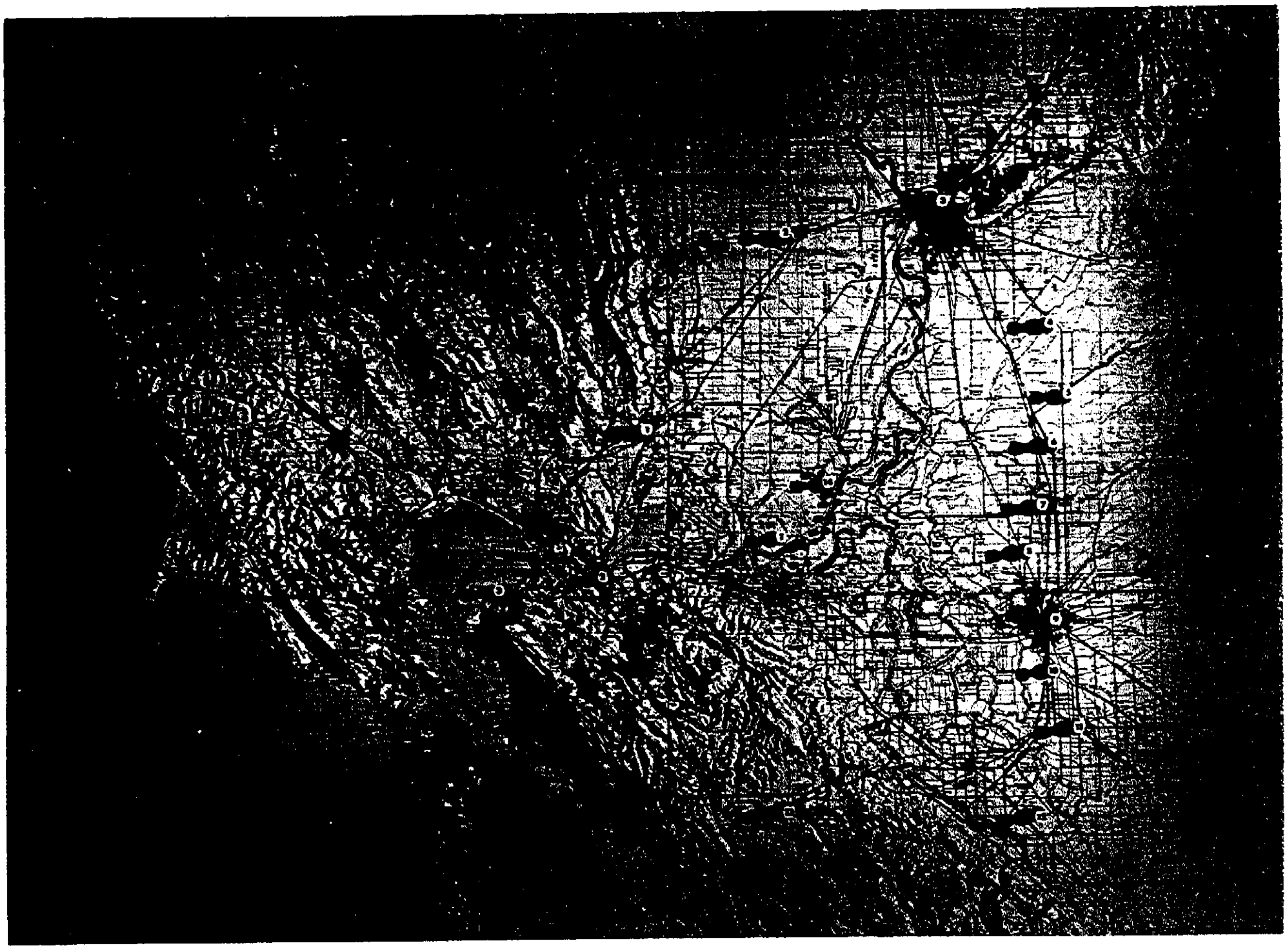

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SUMMARY

Eight atmospheric tracer studies, utilizing $CBrF_3$ and/or SF_6, were conducted from August 31, 1976, through September 14, 1976, within the California Delta Region during four designated meteorological periods. The purpose of these tests was to quantitatively determine the transport and dispersion characteristics of the air passing over the Montezuma Hills. The data base was comprehensive enough to permit accurate mass balances of the tracer; essentially all of the tracer was accounted for by this analysis. Due to the steadiness of the winds, the plume trajectories at 10 km and 50 km downwind of the Montezuma Hills were found to be quite similar. On the average, plumes emitted from the Montezuma Hills during the test periods were transported southeast over Stockton. As a result of the steady nature of the winds, the commonly used Hino correction was found to grossly underestimate the hourly-averaged tracer concentrations computed from 10-second averaged concentrations. A comparison of experimentally determined dispersion parameters with those associated with Pasquill atmospheric stability classes indicated that atmospheric stability generally decreases with increasing distance downwind from the Montezuma Hills. In spite of the complex meteorology and terrain, estimates of tracer concentrations based upon the Gaussian plume model were found to be reasonably accurate. A nomograph was developed to permit rapid calculation of non-reactive pollutant concentrations from tracer data and pollutant emission rates; in the case of NO_2, the oxidation of NO to NO_2 was assumed to be rapid relative to the transport time. The nomograph was used to predict ground level concentrations of pollutants resulting from the projected emissions associated with the proposed Dow complex in the Montezuma Hills. A reasonable correlation was found to exist between the horizontal standard deviation of the wind, σ_θ, and the horizontal dispersion parameter of the plume, σ_y. Air parcel trajectories, based upon Goodin's (1977) numerical solution to the two-dimensional mass balance equation were found to be in excellent agreement with the tracer data. The correlation between σ_θ and σ_y, along with the trajectory analysis provide a means for extending the results of this study to other periods of the year. This investigation indicates where emissions from the Montezuma Hills should be monitored. Finally, these results suggest that further study regarding the chemistry, transport and dispersion of pollutants entering the San Joaquin Valley will be of considerable interest.

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1. Introduction

The economic trade-offs between industrial growth and environmental damage is of growing concern. Industrial development may lead to economic growth in one area while causing economic loss in another. For example, proposed industrialization of the Montezuma Hills, located in the California Delta Region, is expected to stimulate the local economy; however, the possible increase in air pollution associated with new industrial facilities may seriously depress the economy of the inland valleys. Therefore, it is important to quantitatively assess possible monetary losses due to degradation of health and damage to livestock and crops downwind of proposed industrial activities. In order to determine the impact of industrialization upon air quality, it is necessary to characterize the transport and dispersion of pollutants from existing sources as well as the transport and dispersion of pollutants from proposed sources. The complexity of coastal topography and meteorology often requires that atmospheric tracer techniques be used to quantitatively determine the transport and dispersion of pollutants. The data obtained from a tracer field study can be used to help establish plant design criteria in order to insure acceptable air quality downwind. Furthermore, tracer data can be used to indicate where air monitoring stations should be located. Finally, these data are also useful in the development of atmospheric dispersion models.

In order to accomplish these goals in the California Delta Region, eight full-scale tracer studies were conducted during September, 1976. The cost of this tracer study was less than .02% of the capital investments required for the construction and operation of one of the proposed industrial facilities. Atmospheric tracers (SF_6 and $CBrF_3$) were released from property owned by the Dow Chemical Company in the Montezuma Hills, from Martinez, and Pinole. Extensive air sampling and meteorological observation systems were employed during the field study in cooperation with Meteorology Research, Inc. (MRI). The region in which the field study was conducted is shown in Figure 1. The results and conclusions of this investigation are summarized in this Executive Summary; a complete discussion of the results is given in Volume I of this report. The tracer data and pertinent meteorological information are presented graphically in Volume II, Part A, and tabulated in Volume II, Part B. These same data are also available as a computer deck from the California State Air Resources Board.

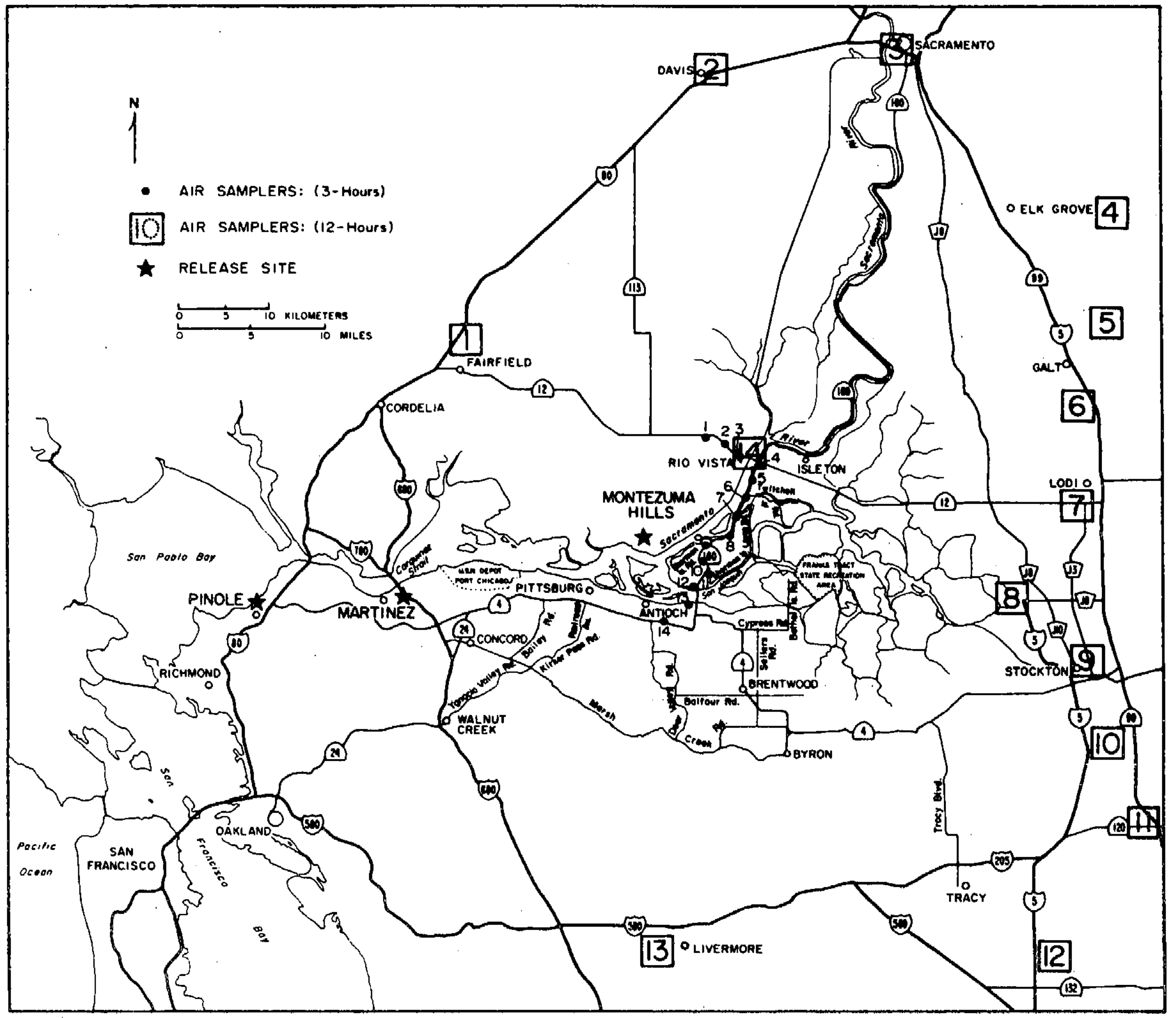

Figure 1. The California Delta Region.

2. Description of the Meteorology and Topography

Interbasin air flow between the Bay Area of San Francisco and the Sacramento and San Joaquin Valleys of central California is characterized during the summer months by a sharp low-level temperature inversion (Miller, 1968) and a strong diurnal sea breeze (Frenzel, 1962; Fosberg and Schroeder, 1966). A northern component of the marine air flows through the Bay Area, channels into the Carquinez Strait and fans across the Delta region of the Sacramento and San Joaquin Rivers (Smalley, 1957). Ultimately, the air passing over the heavily populated and industrialized Bay Area passes from the Delta region into the Sacramento and San Joaquin Valleys (Frenzel, 1962).

The sea breeze diurnal cycle can be divided into four periods of the day (Smith, 1977). During Sea Breeze conditions, from approximately 1300 to 1800, winds are relatively strong throughout the area. The average wind speeds during the Sea Breeze test periods at Martinez, Montezuma Hills, and Stockton were respectively 5 m/sec (11 mph), 7 m/sec (15 mph), and 4 m/sec (9 mph). In the afternoon, the mixing height reaches a maximum due to heating of the land. Typical afternoon mixing depths during the test period were between 1000 and 3000 meters. This pattern is opposite to that which occurs during Nighttime conditions from approximately midnight to 0500. At night, the height of the mixing layer drops to a minimum, typically between 100 and 500 meters. Frenzel (1962) indicated that winds associated with large-scale pressure gradients in the region were such that nighttime land breeze acts to reduce the speed of air flowing from the west, but generally causes no reversal in direction. Average Nighttime wind speeds during the study at Martinez, Montezuma Hills, and Stockton were respectively 4 m/sec (8 mph), 7 m/sec (15 mph), and 3 m/sec (6 mph). Two transition periods separate the Sea Breeze and Nighttime regimes: Pre-Sea Breeze conditions occur from approximately 0600 to 1100 and are characterized by an increase in depth of the nighttime mixing layer and development of the marine air flow; Sea Breeze Tail conditions follow the afternoon period and are typified by a decrease in mixing height and a decrease in the strength of the coastal flow.

As a result of this summertime meteorological cycle, a strong, relatively constant jet of air issues from the Carquinez Strait and fans out into the reaches of the Delta Region and Central Valley. It appears that part of this jet maintains its strength past the Montezuma Hills and then dissipates fairly rapidly just beyond the area. For example, during the two-week period in early September, the average surface wind speed at the Dow site in the Montezuma Hills was 7 m/sec; further downwind, at Brentwood, the average surface wind speed was 2 m/sec.

The existence of this jet suggests that material emitted from the Montezuma Hills may be carried into the Central Valley within a narrow, stable stream of air. Material emitted from the Bay Area into the marine flow may be widely dispersed by the divergence of air from the Carquinez Strait. Pollutants emitted from sources located near one another in the vicinity of the Carquinez Strait may be transported along widely different trajectories into either the Sacramento or San Joaquin Valley.

Terrain effects on air flow appear to be very important in determining pollutant trajectories through the Delta Region. In a Bay Area tracer study utilizing fluorescent particles, Sandberg, et al. (1970), found that the hilly Bay Area terrain, which rises as high as 450 meters, served to deflect westerly marine air flow into northerly and southerly trajectories. Sandberg noted that the presence of low-level temperature inversions enhanced the effects of the Bay Area terrain upon air flow. Sandberg's data indicate that when the width of the plume is larger than the width of the channels associated with the hills, then dispersion increases beyond that over flat terrain; however, when the width of the plume is smaller than the width of the channels, containment by the terrain can lead to decreased dispersion.

3. Experimental Procedure

Eight tracer studies were conducted from August 31, 1976, through September 14, 1976, within the Delta Region during the four designated meteorological periods. During seven of the tests, either SF_6 or $CBrF_3$ was released from property owned by Dow Chemical in the Montezuma Hills. During the two tests where $CBrF_3$ was used, the SF_6 tracer was emitted upstream; SF_6 was released from Martinez during Test 2, and from Pinole during Test 7, in hopes of determining the origin and dispersion of the air passing over the Montezuma Hills. The final test involved only a release of SF_6 from Pinole. In all cases the tracer was released from a height of about 5 meters above the ground. Releases from the Dow site covered all four meteorological periods; the releases from Martinez and Pinole were conducted during Sea Breeze and Pre-Sea Breeze conditions. The release schedule, the release locations, and release rates are given in Table 1.

During each test day, air samples were collected via automobile traverses involving three to five, two-person teams. Automobile traverses were made by having the passenger in each car take 10-second grab samples in 30 cm^3 plastic syringes. Generally, samples were collected every 0.1, 0.2, 0.5, or 1.0 miles, depending upon the distance from the release point and the steadiness of the wind. Descriptions of the traverses are given in Volume I. Traverse paths were determined in the field from real time wind data. Analysis of samples collected during the early part of each release was used to establish traverse routes for the rest of the test.

Personnel from Meteorology Research, Inc. (MRI) obtained air samples

TABLE 1

TRACER RELEASE DATA

Date	Test	Location* of SF_6 Release	Release Period (PDT)	Release Rate (grams/sec)	Location of $CBrF_3$ Release	Release Period	Release Rate
8/31/76	1	Montezuma Hills	1200-1700	10.6 1.01 tons/day	-	-	-
9/2/76	2	Martinez	1100-1600	11.4 1.08 tons/day	Montezuma Hills	1300-1500	16.6 1.58 tons/day
9/5/76	3	Montezuma Hills	0000-0500	9.5 0.90 tons/day	-	-	-
9/6/76	4	Montezuma Hills	1800-2300	10.8 1.03 tons/day	-	-	-
9/9/76	5	Montezuma Hills	1130-1330	10.7 1.02 tons/day	-	-	-
9/10/76	6	Montezuma Hills	0600-1100	10.5 1.00 tons/day	-	-	-
9/13/76	7	Pinole	0600-1500	11.5 1.09 tons/day	Montezuma Hills	0900-1100	16.0
						1300-1400	16.0 1.52 tons/day
9/14/76	8	Pinole	0730-1300	10.9 1.04 tons/day	-	-	-

* Exact Tracer Release Locations: (1) Montezuma Hills: tracer was released from a truck parked by the Dow Chemical air quality monitoring station. The monitoring station is located approximately 4.3 km east of Collinsville and 2 km north of the Sacramento River. (2) Martinez: tracer was released from the parking lot of the Mountain View Sanitary District Sewage Plant at the end of Arthur Road. (3) Pinole: tracer was released from the parking lot of the Pinole police station on Pear Street.

in a manner similar to the automobile traverse teams from an airplane traveling downwind of the release at various heights and locations. Air samples were also obtained during vertical spirals through the mixing layer; samples were typically taken at vertical intervals of 100 or 200 feet. During Test 6, Caltrans provided a plane and personnel for three airborne traverses from Sacramento to Stockton. Descriptions of the airborne traverses and spirals are given in Volume I.

A total of 42 sequential hourly air samplers were located at 28 sampling sites; the locations of the sites are shown in Figure 1. Equipment which permitted the sequential collection of hourly averaged air samples for 12 hours were positioned at 14 locations, primarily along Highway 99. An additional 14 locations along Highway 160 (10 km east of the Dow site) were designated for the positioning of battery-powered samplers which permitted the sequential collection of hourly averaged samples for three hours. These samplers were used during Tests 1 and 2. During the eight tests, 4508 automobile traverse samples, 1258 airborne traverse samples, 330 airborne spiral samples, 1721 hourly averaged 12-hour board samples, and 153 hourly averaged 3-hour board samples were collected; the total number of samples collected was 7970.

Air samples were analyzed for SF_6 and $CBrF_3$ using electron capture gas chromatography. A typical chromatogram is shown in Figure 2; additional details concerning the gas chromatographs are available in Volume I. Twelve chromatographs and two digital integrators were set up in a room at the California Holiday Lodge, Fairfield, California. Only eight of the chromatographs were used during the test; four were used to analyze for SF_6 alone and four were set up to analyze for both tracers.

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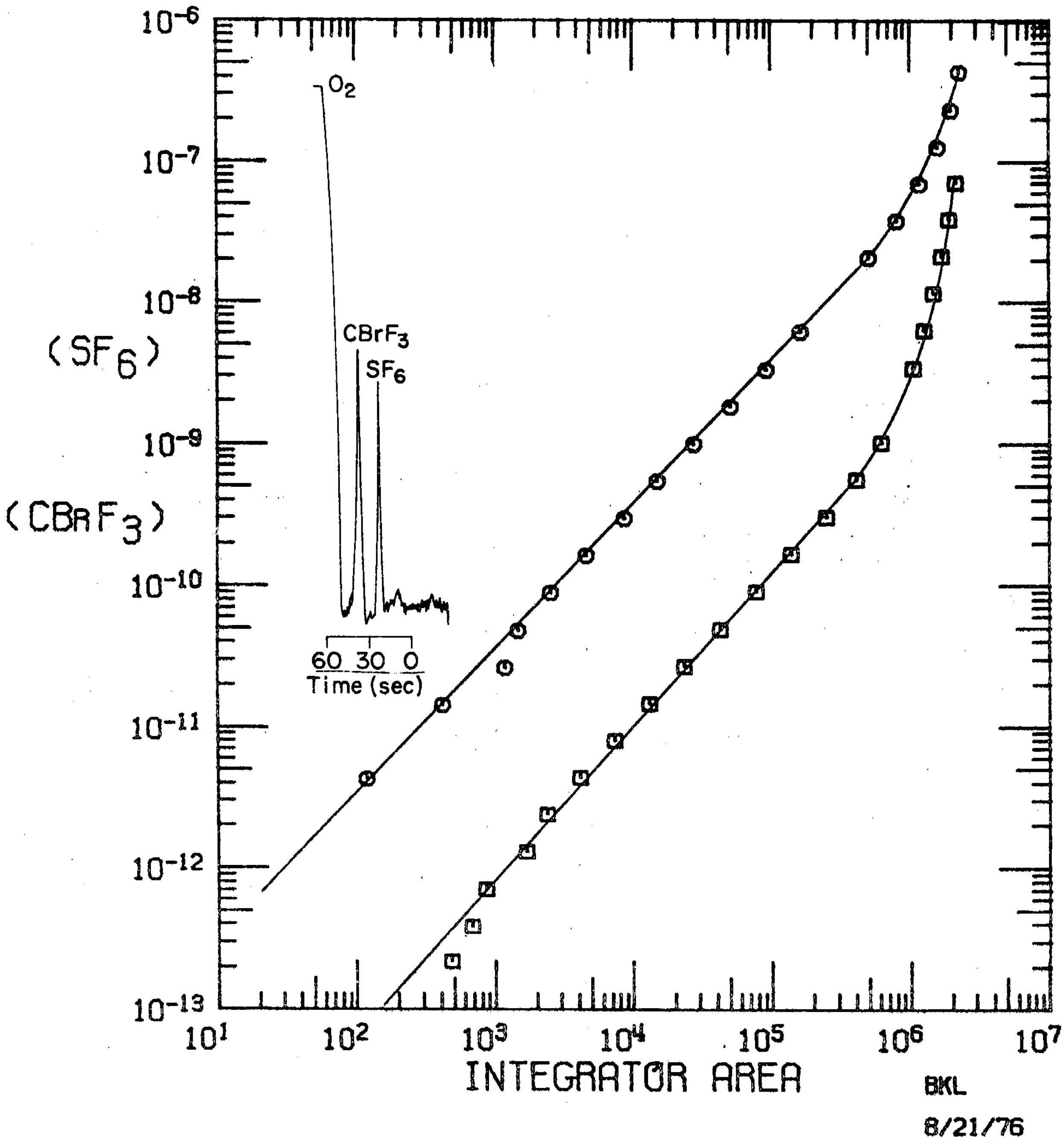


Figure 2. Typical dual tracer chromatogram (inset): $[SF_6]$ = 6ppt $[CBrF_3]$ = 310 ppt. Typical dual tracer calibration curves.

Air samples were returned each day to the lab for analysis. All of the samples from one test were analyzed before the next began. Calibration was done using an exponential dilution method. Calibration results show that concentrations down to 10^{-12} parts SF_6 per part air and 10^{-11} parts $CBrF_3$ per part air could be detected at a signal-to-noise ratio of better than 3 to 1. Typical calibration curves are shown in Figure 2. The gas chromatographs were calibrated before and after the field test period. During the tests, the instruments were cross-checked periodically for reproducibility. The calibration of the tracer data changed by approximately 7% among the gas chromatographs used to analyze SF_6 alone. Calibration results for the remaining gas chromatographs changed by 25% for SF_6 and 20% for $CBrF_3$. Degradation of the columns and detectors due to atmospheric contaminants in the air samples was the probable cause for the changes in the calibrations. Previous experience has shown that the presence of halogenated solvents in air samples can, over an extended period of use of the chromatograph, contaminate the detector and column. Uncertainty in the tracer concentrations is estimated to range from less than 5% for most of the samples, to no more than 25% for a limited number of samples. Details of the calibration are given in Appendix A, Volume I.

Meteorological data, consisting of surface and elevated wind speeds, wind directions, mixing height estimations, cloud cover reports, and standard deviations of the horizontal wind, were collected from a variety of agencies or were obtained from MRI. Personnel from MRI were responsible for collection of airborne tracer samples and air quality data as well as the compilation and analysis of the available meteorological data. Wind data collection points are shown in Figure 3.

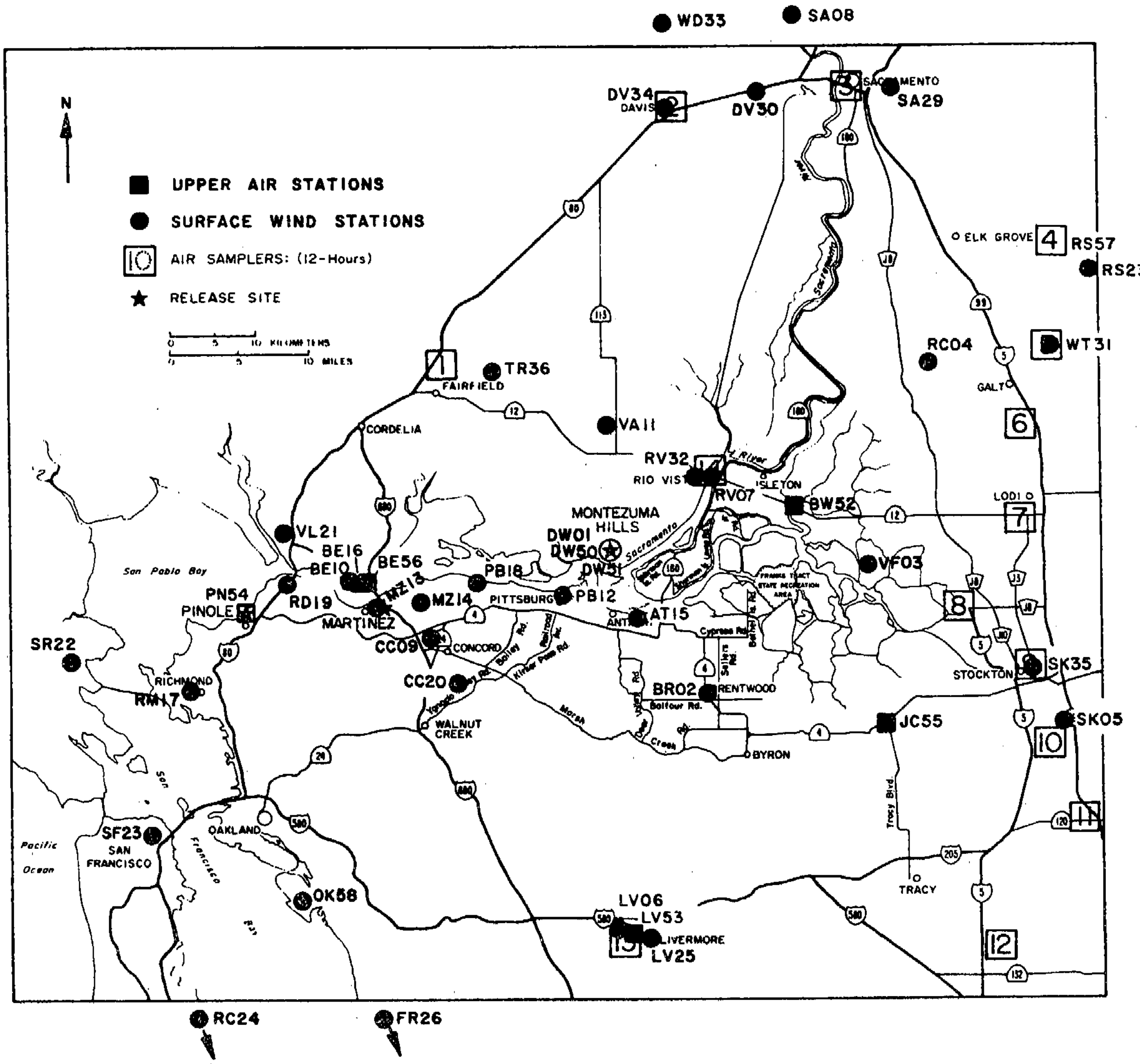


Figure 3. Location of Surface Wind and Upper Air Data Stations.

4. Synopsis of Tracer Tests

TEST 1, 8/31/76:

The purpose of the first tracer test was to probe the transport and dispersion of pollutants emitted from the Montezuma Hills under afternoon Sea Breeze conditions. SF_6 was released at a constant rate from 1200 to 1700 PDT. Meteorological conditions were typical of the Sea Breeze pattern.

Automobile traverse data indicated that the tracer plume crossed Highway 160 almost directly east of the Dow release site. The plume apparently curved south and reached the Stockton-Tracy area around 1700 PDT. An overview of typical automobile traverse data is shown in Figure 4. This pattern is confirmed by the hourly average tracer data shown in Figure 5. The hourly averaged fluctuations of the plume are apparent in Figure 6. The tracer data indicate that under the test conditions, emissions from the Montezuma Hills would ultimately be transported south into the San Joaquin Valley.

TEST 2, 9/2/76:

The purpose of Test 2 was to tag the air moving over the Montezuma Hills during the afternoon Sea Breeze period. Two atmospheric tracers were used: SF_6 was introduced upstream at Martinez near existing industrial pollutant sources; $CBrF_3$ was released from the Montezuma Hills. SF_6 was released from 1100 to 1600 PDT, and $CBrF_3$ was released from 1300 to 1500 PDT.

The air tagged by the SF_6 tracer at Martinez generally passed south of the Montezuma Hills. However, it did pass through the Stockton-Tracey area, as did the emissions from the Montezuma Hills. Figures 7 and 8 are

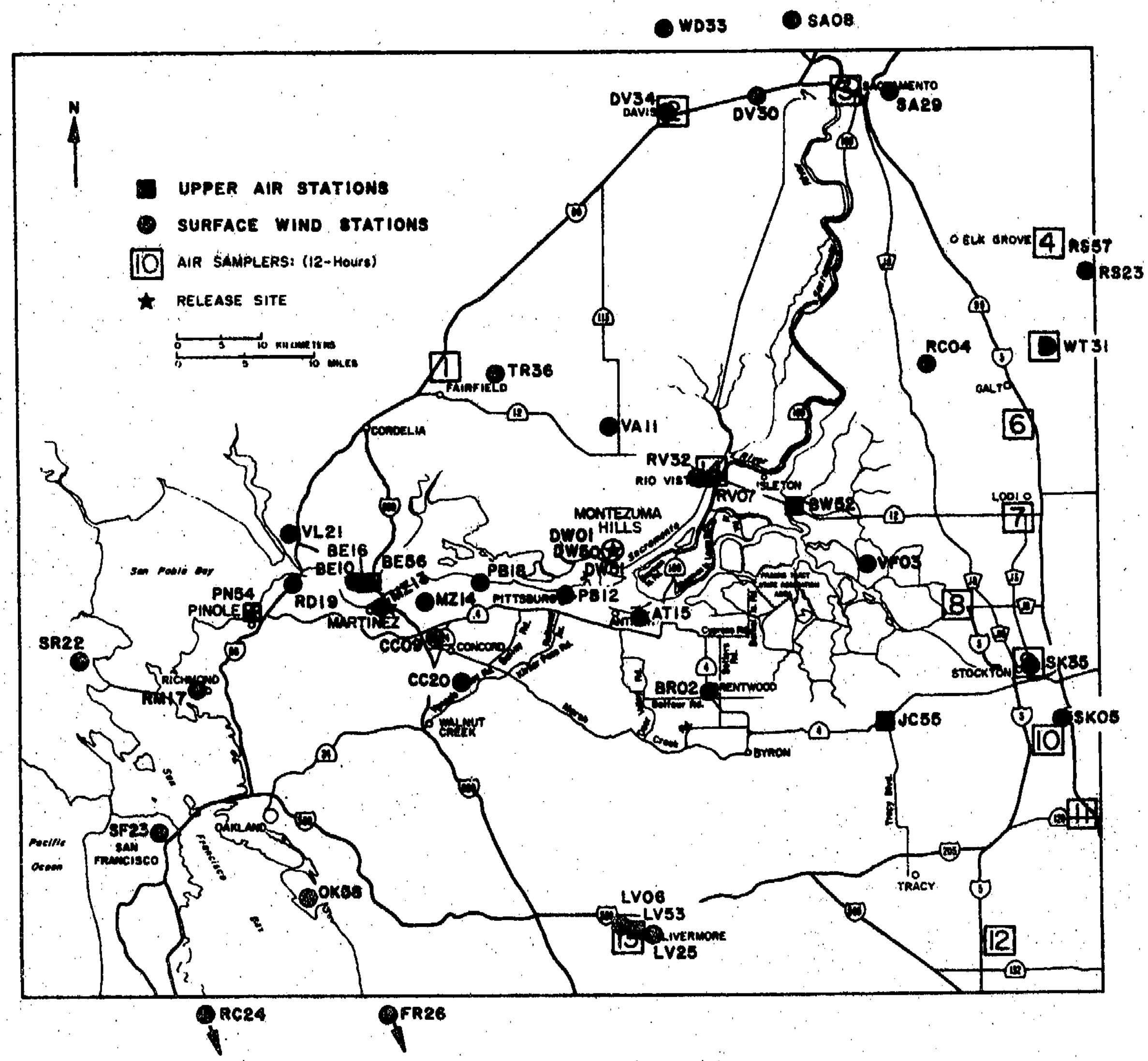


Figure 3. Location of Surface Wind and Upper Air Data Stations.

Montezuma Hills under the test conditions ultimately pass into the San Joaquin Valley. However, under nighttime conditions, it appears that much higher concentrations may be found farther downwind than during daytime periods.

TEST 4, 9/6/76:

The purpose of Test 4 was to determine the characteristics of the transport and dispersion of pollutants emitted from the Montezuma Hills under the Sea Breeze Tail meteorological condition. SF_6 was released at a constant rate from 1800 to 2300 PDT. Winds were strong ($\sim$ 7 m/sec at the Dow site) from the west. The average depth of the mixing layer was 510 meters.

Higher concentrations were observed along Highway 160 during this test than during the nighttime test. The peak value, as indicated in Figure 14, was 11,900 ppt. The plume trajectory crossed Highway 160 6 Km north of the Highway 160-4 junction and passed Highway 99 at Stockton. As indicated in Figure 15, the plume was very steady over Stockton from 2000 to 2300 PDT; the plume shifted south towards Manteca between 2300 and 0200 PDT as shown in Figures 16 and 17. Significant SF_6 levels were recorded at Manteca until 0700 PDT (Figure 18).

The patterns in this test were very similar to those from previous tests. Plumes emitted from the Montezuma Hills were transported east and south into the San Joaquin Valley. The high concentrations observed during this test resulted from the steady wind, a stable atmosphere, and a low mixing depth.

TEST 5, 9/9/76:

The purpose of this test was to study the transport and dispersion of pollutants emitted from the Montezuma Hills as the sea breeze developed. SF_6 was released at a steady rate from 1130 to 1330 PDT. The release was stopped after it became apparent that the sea breeze was not developing. Winds during the test were generally from the north at low speeds. The average mixing layer was estimated to extend to 1900 meters.

Because the sea breeze did not develop as in previous tests, the tracer trajectories do not resemble those of previous tests. The automobile traverse data shown in Figure 19 indicate that the plume moved south through Antioch towards Livermore. Surface wind streamlines suggest that flow through Livermore would have caused the plume to curve east and south towards Modesto in the San Joaquin Valley. The peak values of 180 ppt were relatively low compared to previous results.

TEST 6, 9/10/76:

The purpose of the sixth test was to examine the transport and dispersion of pollutants emitted from the Montezuma Hills under Pre-Sea Breeze conditions. SF_6 was released at a constant rate from 0600 to 1100 PDT. Northwesterly flow prevailed in the area, and the average mixing depth reached 1240 meters.

Although SF_6 concentrations along Highway 160 were as high as 9526 ppt, concentrations along Highway 99 were no greater than 20 ppt, as shown in Figure 20. It is possible that traverses along Highway 99 did not cross the plume centerline. Airborne data were collected for the first time during Test 6; the vertical structure of the plume 20 Km downwind observed in an airborne spiral is shown in Figure 21. Although these data suggest that the plume centerline moved aloft at 122 meters, because the plume was spiraling over a horizontal radius of 400 meters, it is possible that samples at the lowest levels were not taken in the plume.

Both the automobile and airborne data indicate that the plume initially moved east from the Dow site. The automobile data taken at 1100 PDT suggest that the trajectory curved south to Tracy. Airborne data taken from 1200-1239 at 183 meters, shown in Figure 22, and hourly averaged data observed between 1200 and 1600 PDT indicate that the plume crossed Highway 99 between Lodi and Stockton during the afternoon (see Figure 23).

This pattern agrees with the general patterns observed during the previous tests. Emissions from the Montezuma Hills are transported east across Highway 160 and then cross somewhere along Highway 99 in a zone extending from Lodi to Manteca.

TEST 7, 9/13/76:

The purpose of this test was to tag the air upstream of the Montezuma Hills during the development and onset of the afternoon sea breeze. SF_6 was released at a constant rate from Pinole between 0600 and 1500 PDT. Flow over the Dow site was monitored by releasing $CBrF_3$ at a steady rate from 0900-1100 PDT and 1300-1400 PDT. Winds were generally from the west throughout the area. The average mixing height reached 830 meters.

The automobile traverse data indicated that the SF_6 plume moved through the Carquinez Strait and passed partially over the Montezuma Hills; the $CBrF_3$ plume, shown in Figure 24, conformed to the typical patterns observed previously along Highway 160. Later traverses shown in Figure 25 suggested that the plume passing through Carquinez Strait split; one portion appeared to continue east towards the Montezuma Hills while the other turned south into the Walnut Creek area. Airborne traverse data confirmed the presence of SF_6 downwind of the Montezuma Hills; the data in Figure 26 indicate that the plume was vertically well-mixed to at least 427 meters. The divergence of the plume across the Delta region was also apparent in the hourly averaged data. No well-defined plume was observed along Highway 99; low levels of SF_6 were found from Elk Grove south to Livermore. The data from Test 7 again show that emissions from points upstream of the Montezuma Hills can be transported east across the Delta region and south through Stockton into the San Joaquin Valley.

TEST 8, 9/14/76:

The purpose of the final tracer test was to study the transport and dispersion of pollutants in air flowing through the Carquinez Strait during development of the afternoon sea breeze. SF_6 was released at a constant rate from Pinole between 0730 and 1300 PDT. Winds during the test were relatively strong (4 m/sec) from the west; the average mixing height was 1200 meters.

Automobile and airborne traverse data indicated that the plume was transported east through the Carquinez Strait past the Montezuma Hills. The airborne data shown in Figure 27 depict the vertical structure of the plume 17 Km downwind of Pinole. The plume was not vertically well-mixed, but had diffused to at least 427 meters above the surface at this distance.

The tracer plume appeared to behave similarly to that in Test 7 during the mid-morning hours. No data were collected along Highway 99 during this test.

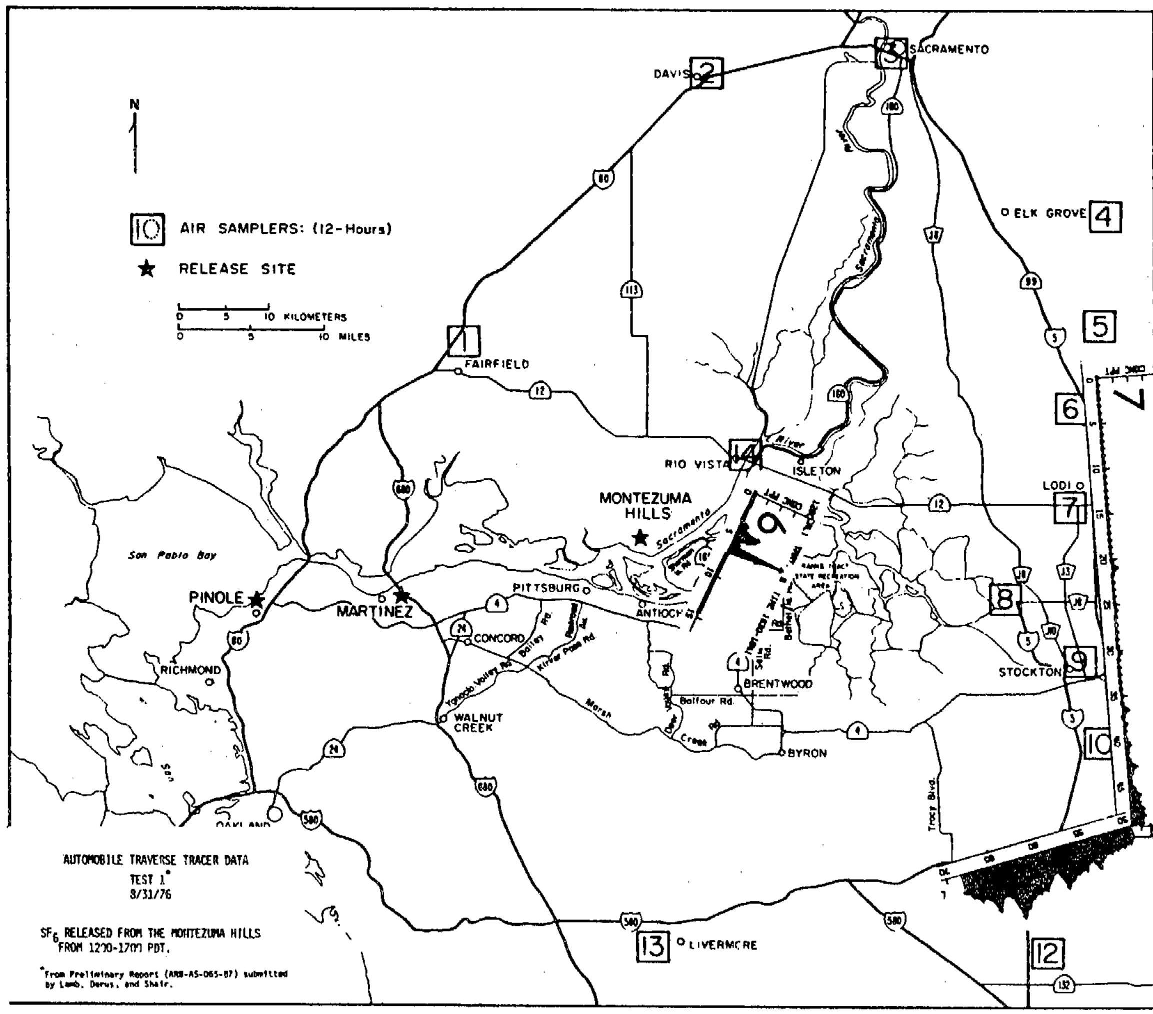


Figure 4. Overview of automobile SF_6 data.

TEST 1

8/31/76

Auto Traverses:

6 1630 - 1641 PDT, SF_6(max) = 1223 ppt

7 1701 - 1753 PDT, SF_6(max) = 64 ppt

SF_6 released from the Montezuma Hills from 1200-1700 PDT.

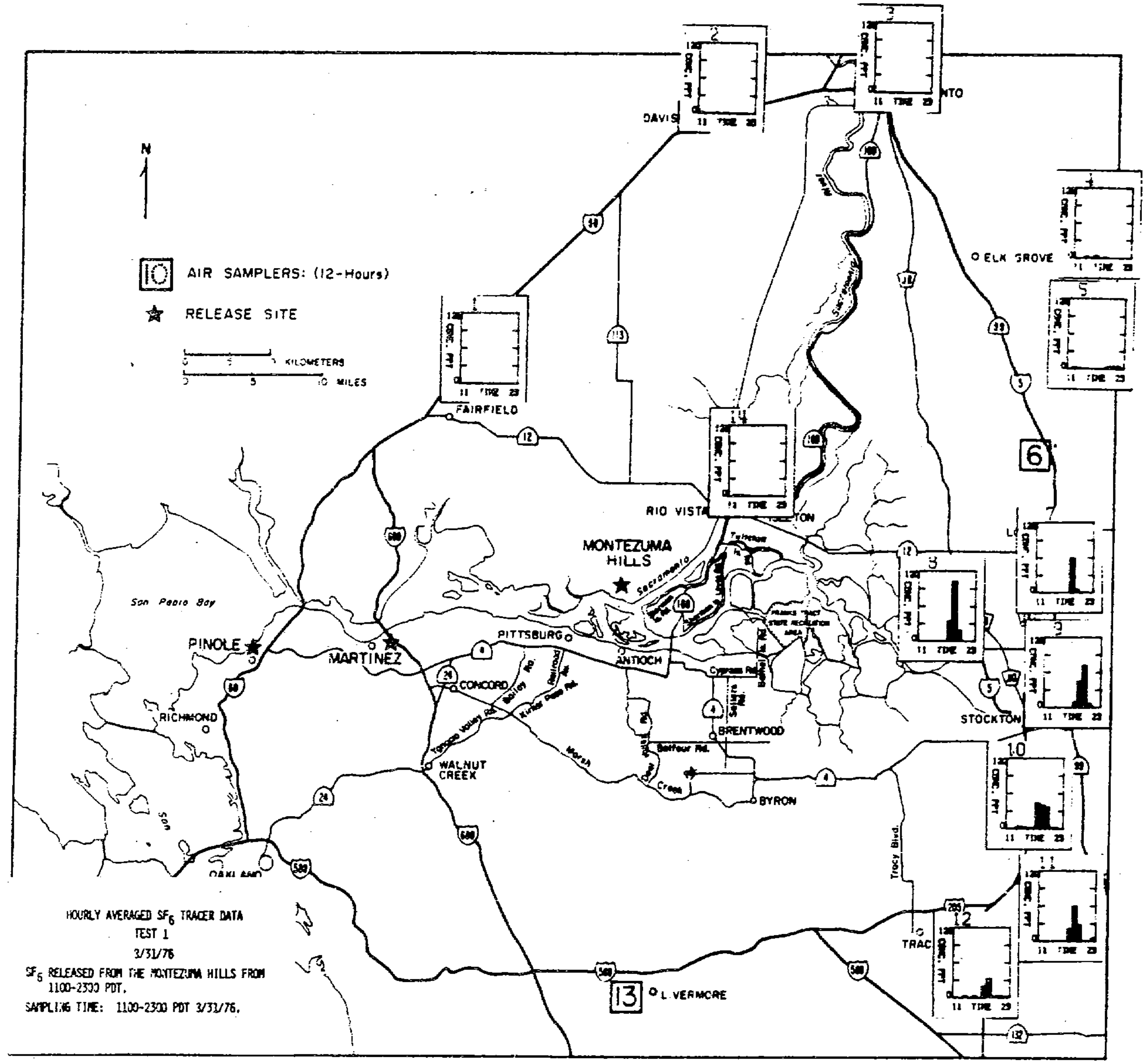


Figure 5. Overview of hourly averaged SF_6 data. Full scale SF_6 = 120 ppt.

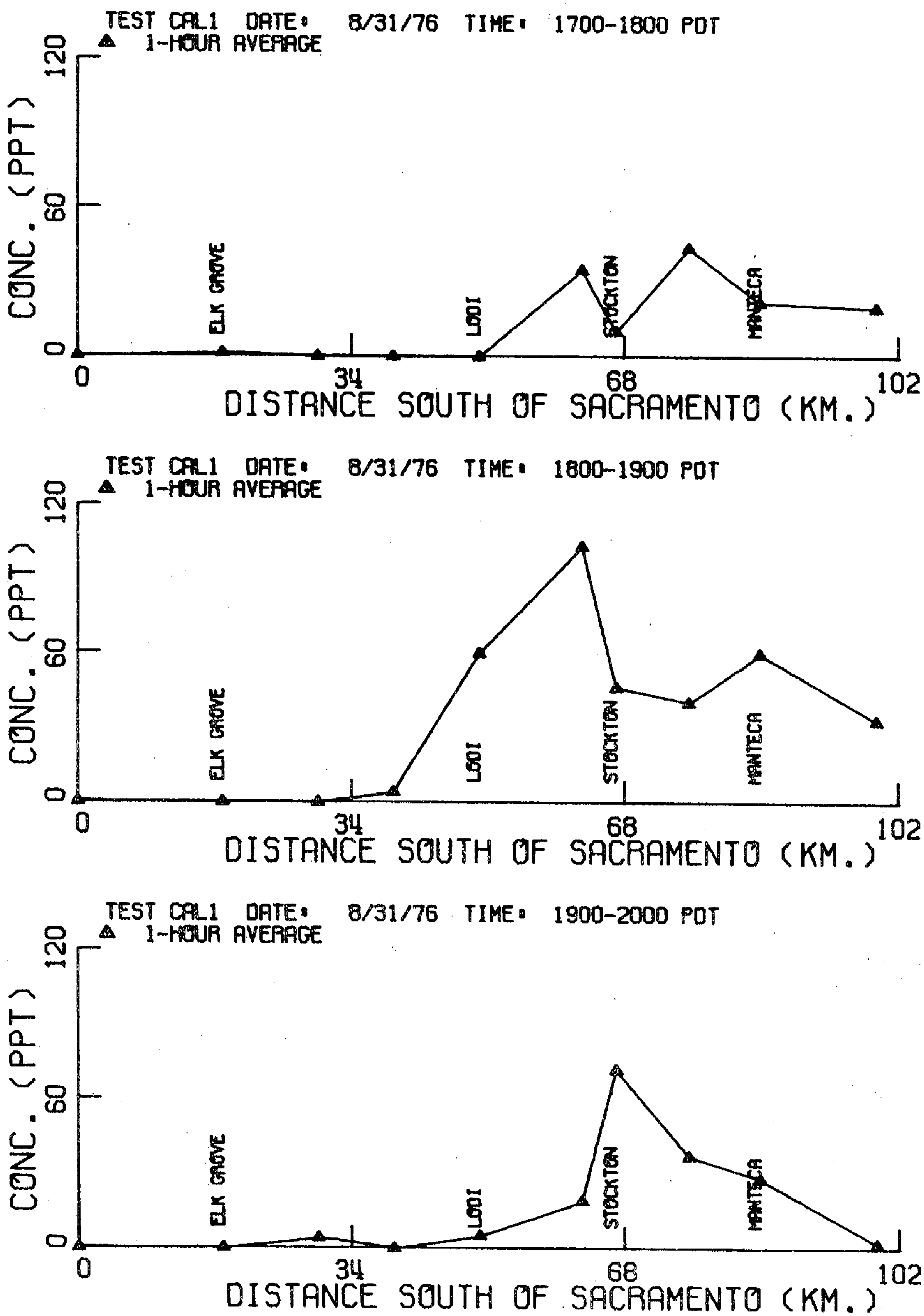


Figure 6. Hourly averaged crosswind profiles measured along Highway 99.

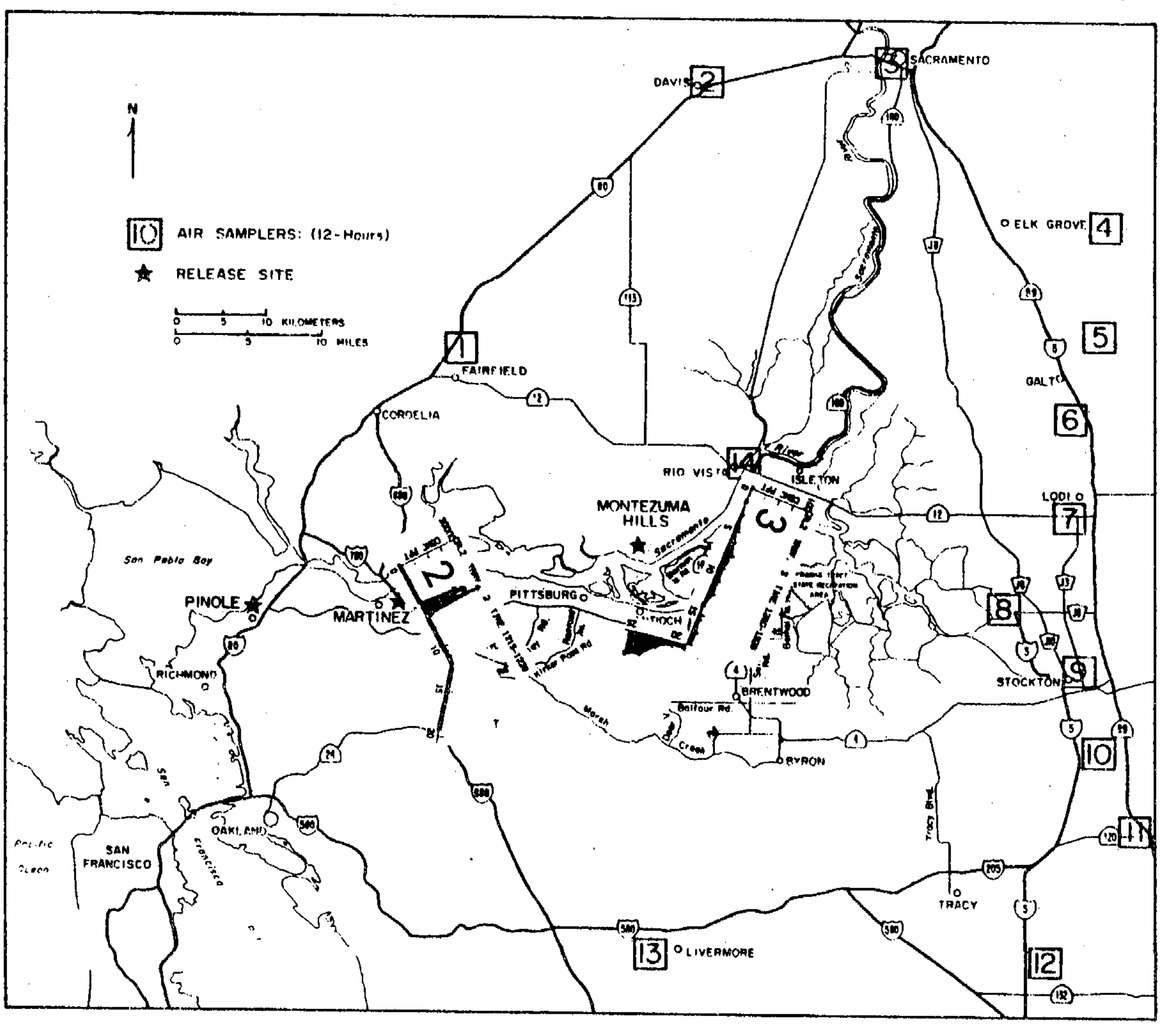


Figure 7. Overview of automobile traverse SF_6 data.

TEST 2

9/2/76

Auto Traverses:

2 1215 - 1228 PDT, SF_6(max) = 30,000 ppt

3 1240 - 1328 PDT, SF_6(max) - 41 ppt

SF_6 released from Martinez from 1100-1600 PDT.

$CBrF_3$ released from the Montezuma Hills from 1300-1500 PDT.

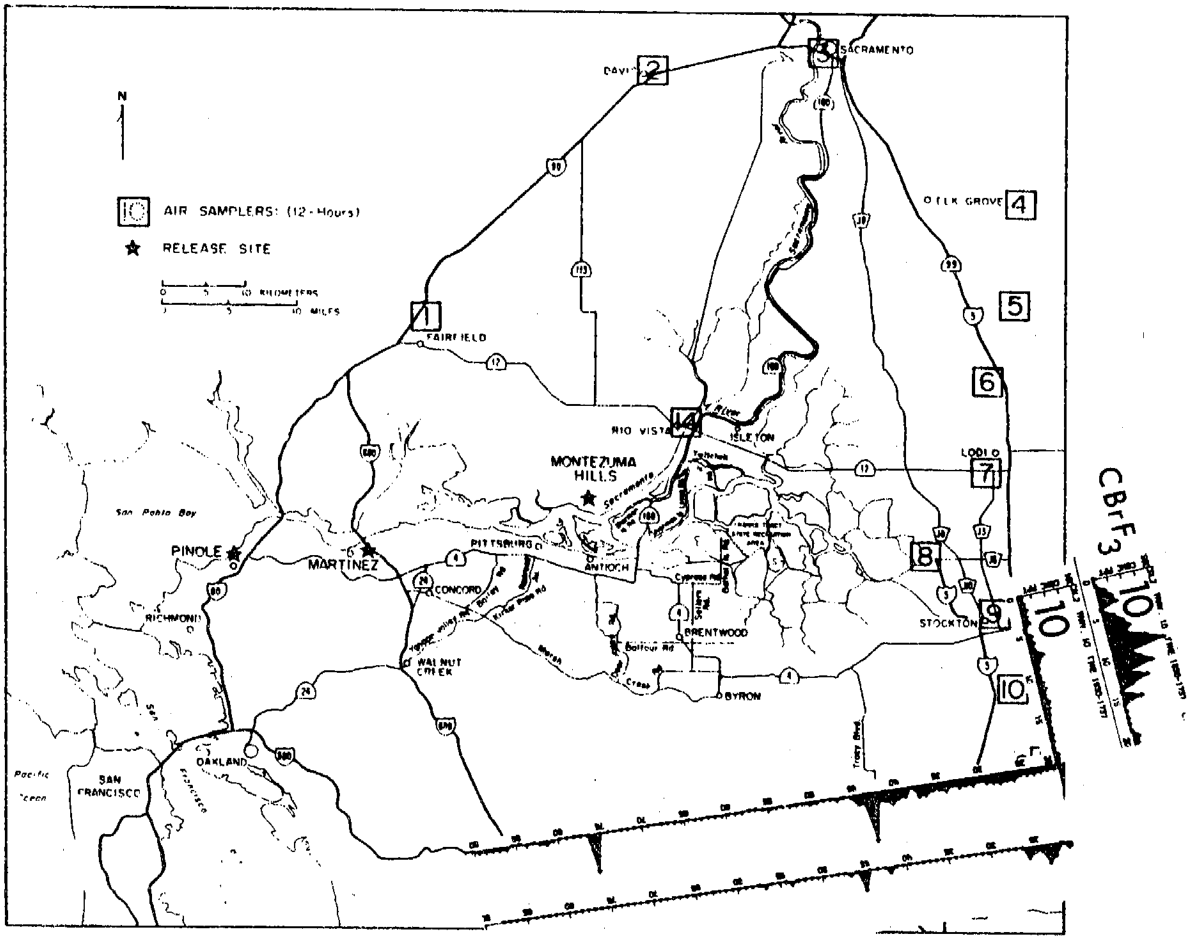


Figure 8. Overview of automobile traverse SF_6 and $CBrF_3$ data.

TEST 2

9/2/76

Auto Traverse:

10 1630-1737 PDT, SF_6(max) = 91 ppt.

1630-1737 PDT, $CBrF_3$(max) = 300 ppt.

SF_6 released from Martinez from 1100-1600 PDT.

$CBrF_3$ released from the Montezuma Hills from 1300-1500 PDT.

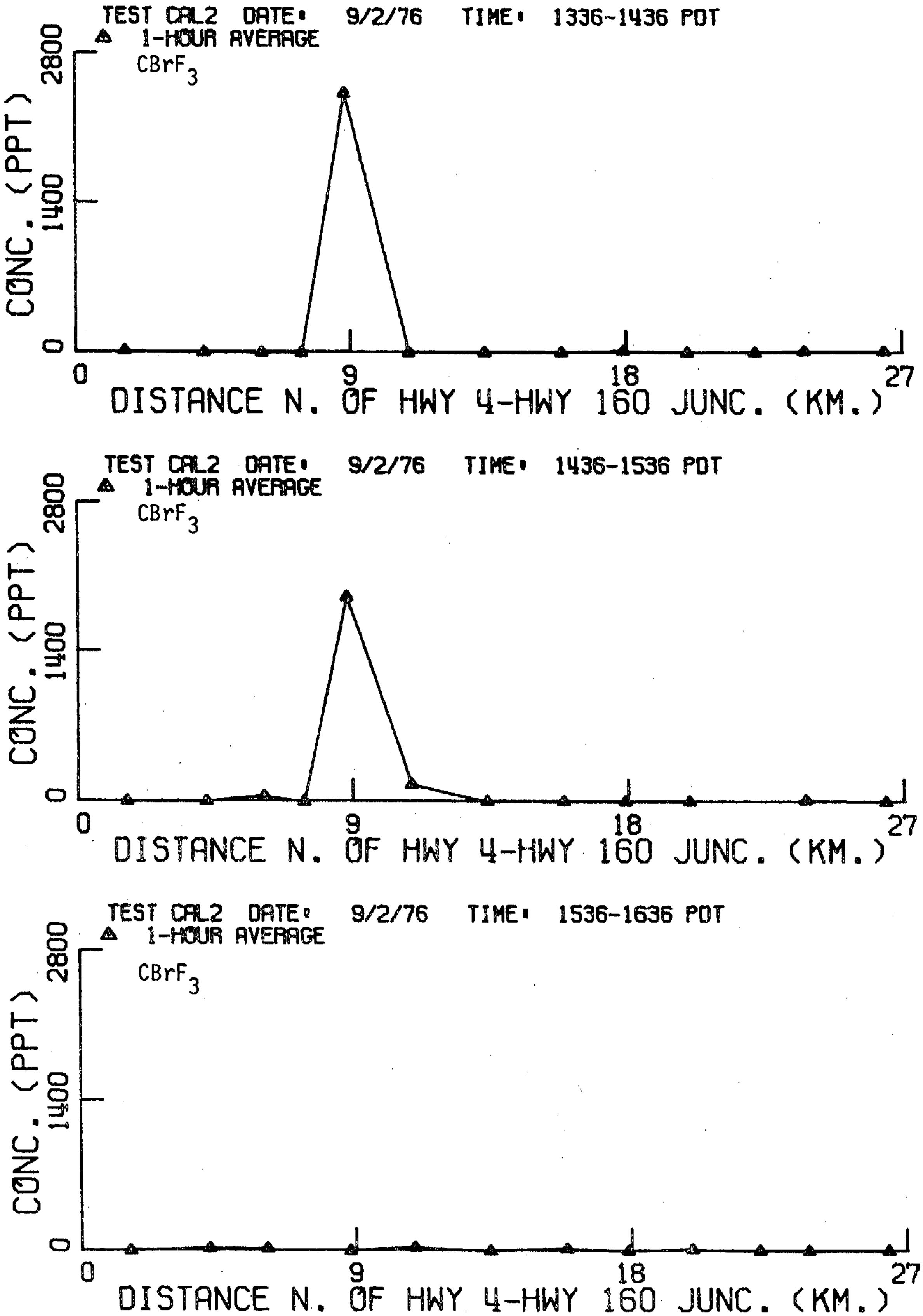


Figure 9. Hourly averaged $CBrF_3$ crosswind profiles measured along Highway 160.

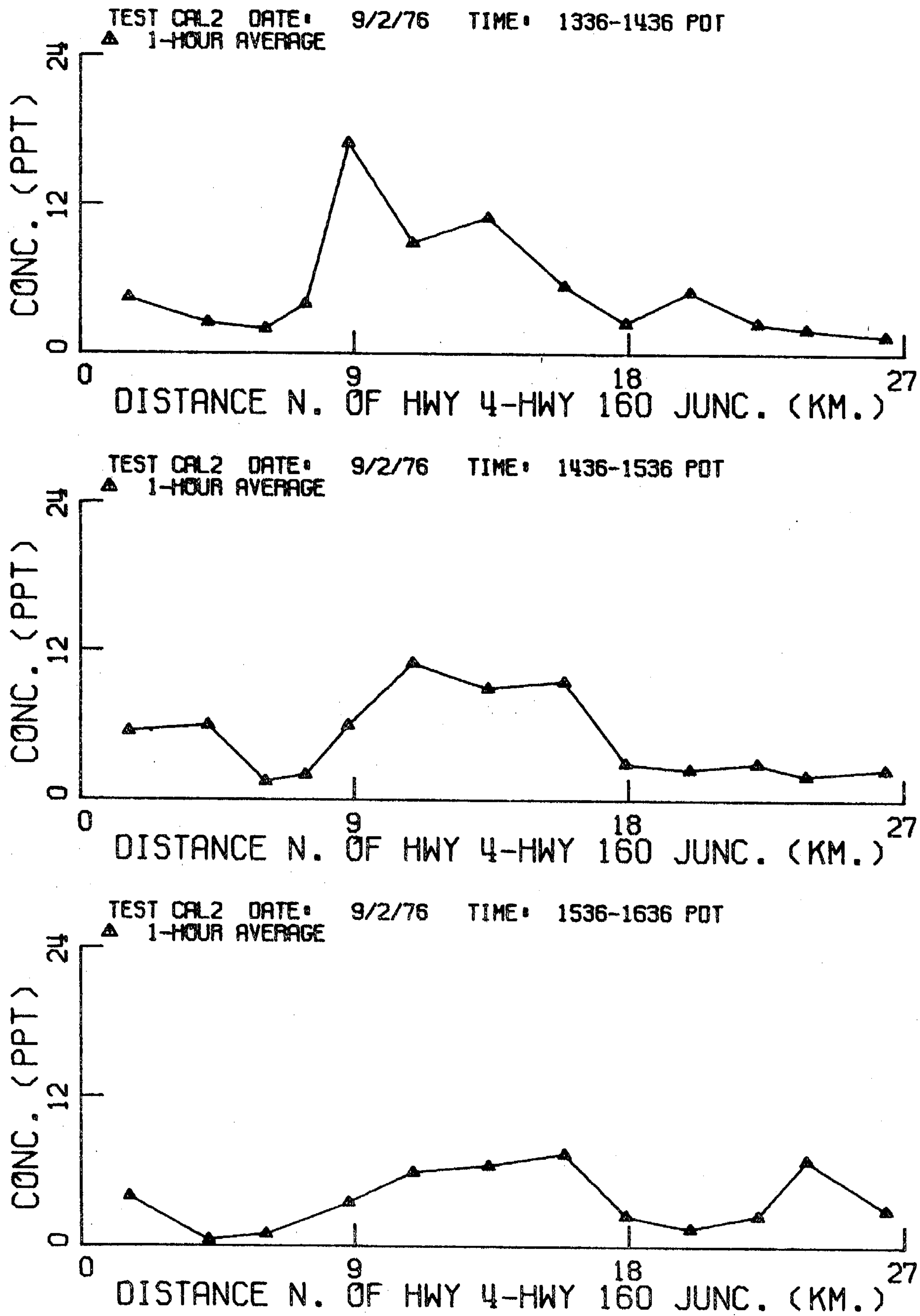


Figure 10. Hourly averaged SF_6 crosswind profiles measured along Highway 160.

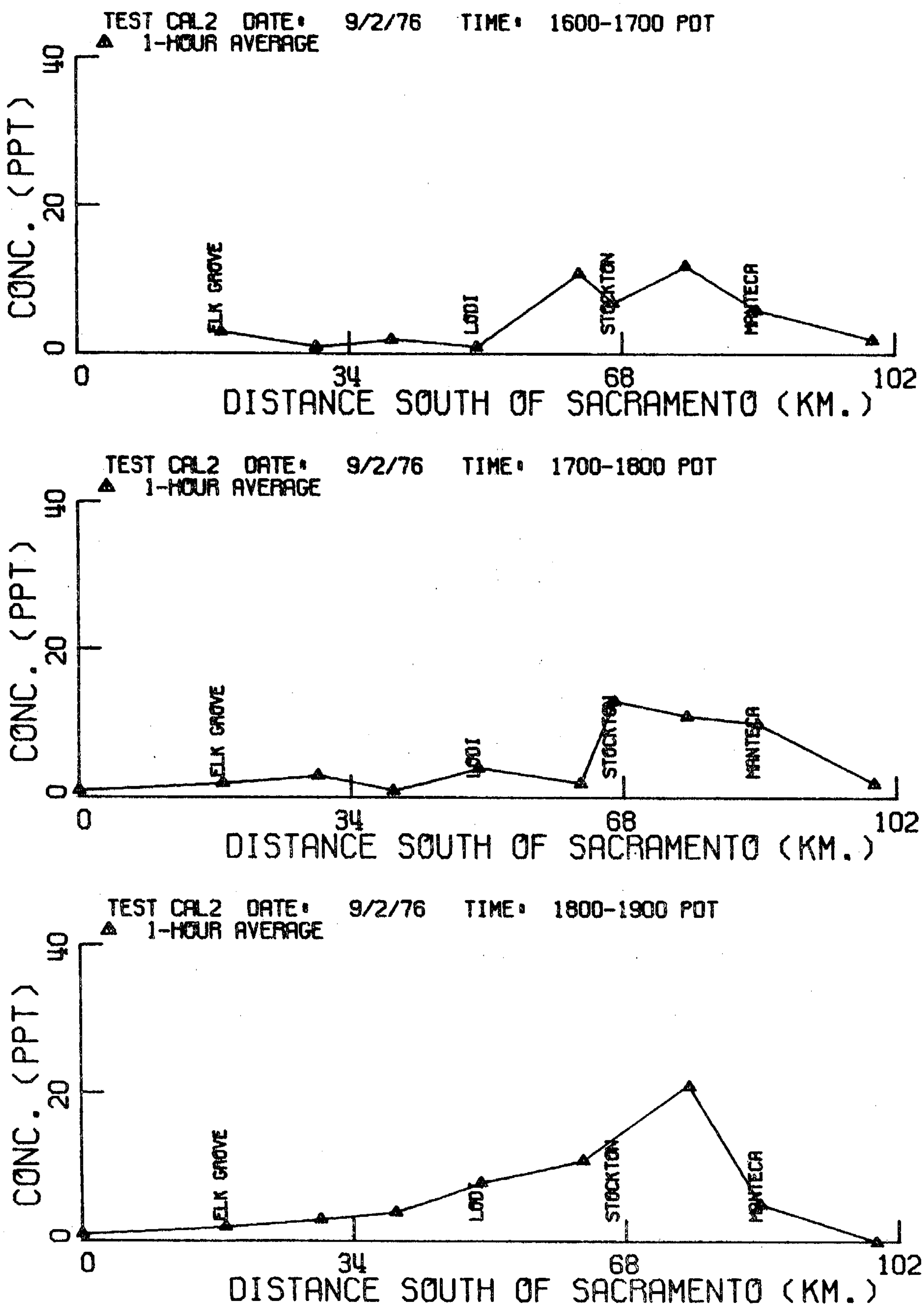


Figure 11. Hourly averaged SF_6 crosswind profiles measured along Highway 99.

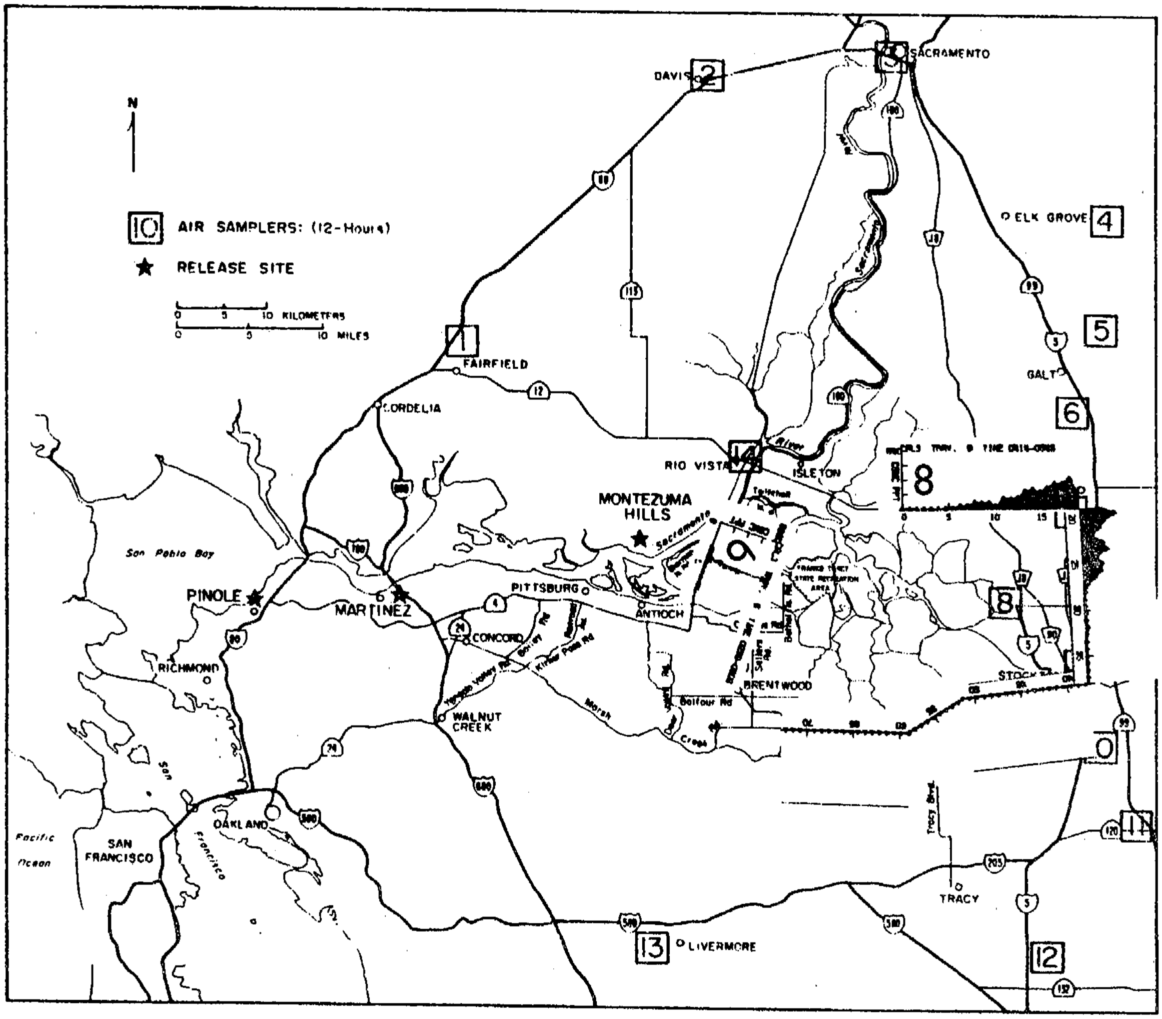


Figure 12. Overview of automobile traverse SF_6 data.

TEST 3

9/5/76

Auto Traverses:

6 0259 - 0306 PDT, SF_6(max) = 8660 ppt

8 0414 - 0545 PDT, SF_6(max) = 370 ppt

SF_6 released from the Montezuma Hills from 0000-0500 PDT.

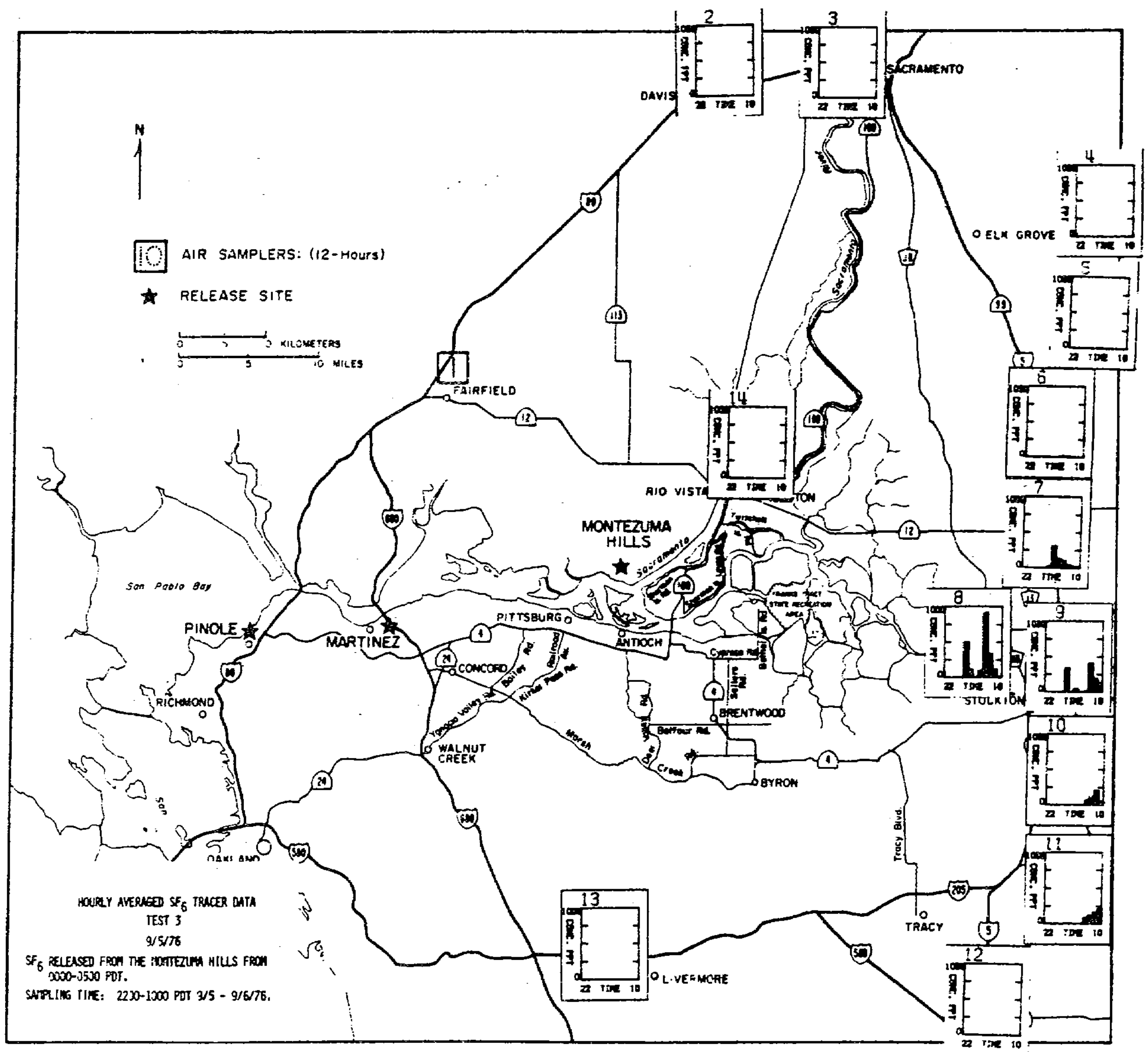


Figure 13. Overview of hourly averaged SF_6 data. Full scale SF_6 = 1000 ppt.

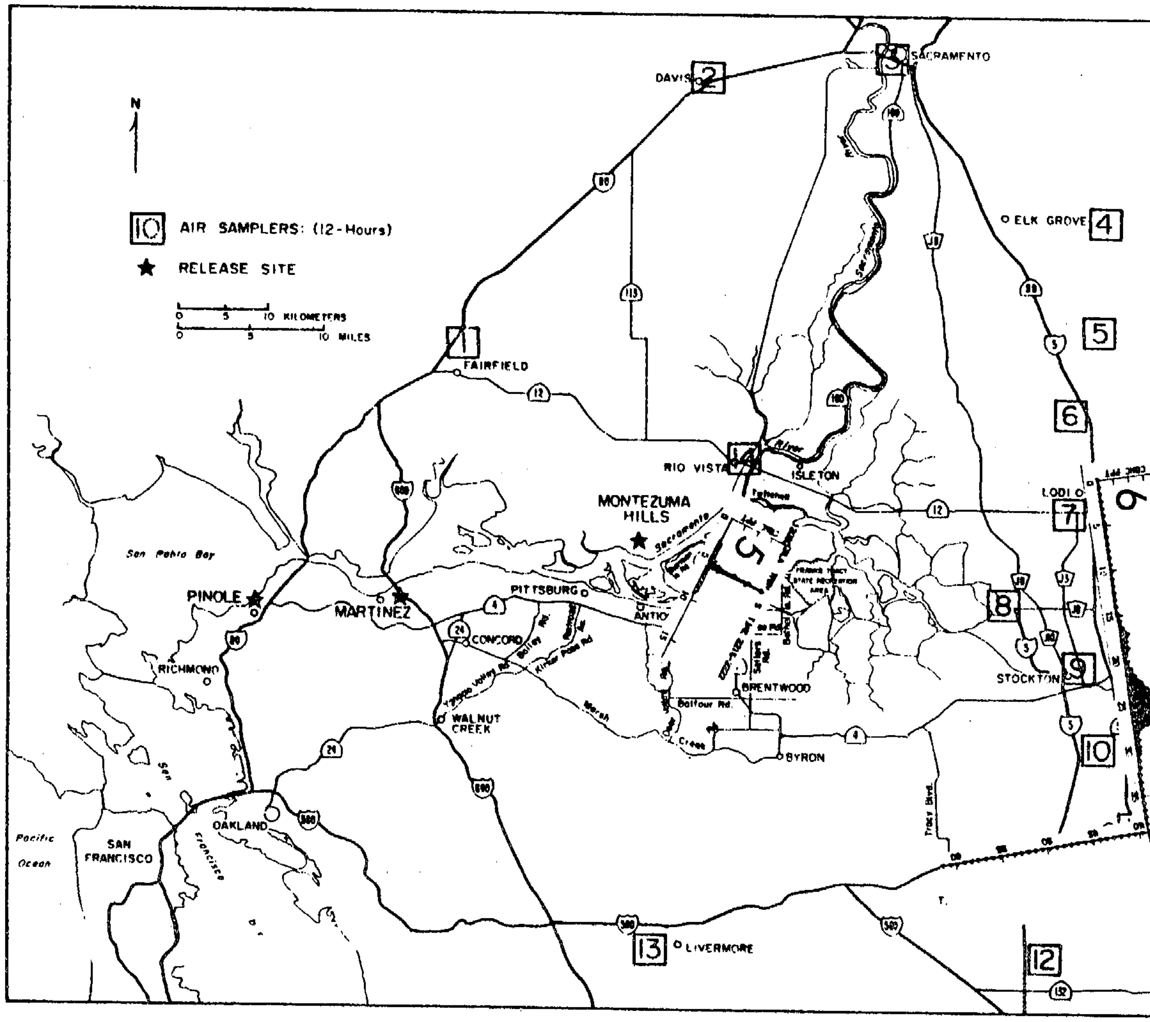


Figure 14. Overview of automobile traverse SF_6 data.

TEST 4

9/6/76

Auto Traverses:

5 2214 - 2222 PDT, SF_6(max) = 11,900 ppt

6 2232 - 2320 PDT, SF_6(max) = 553 ppt

SF_6 released from the Montezuma Hills from 1800-2300 PDT.

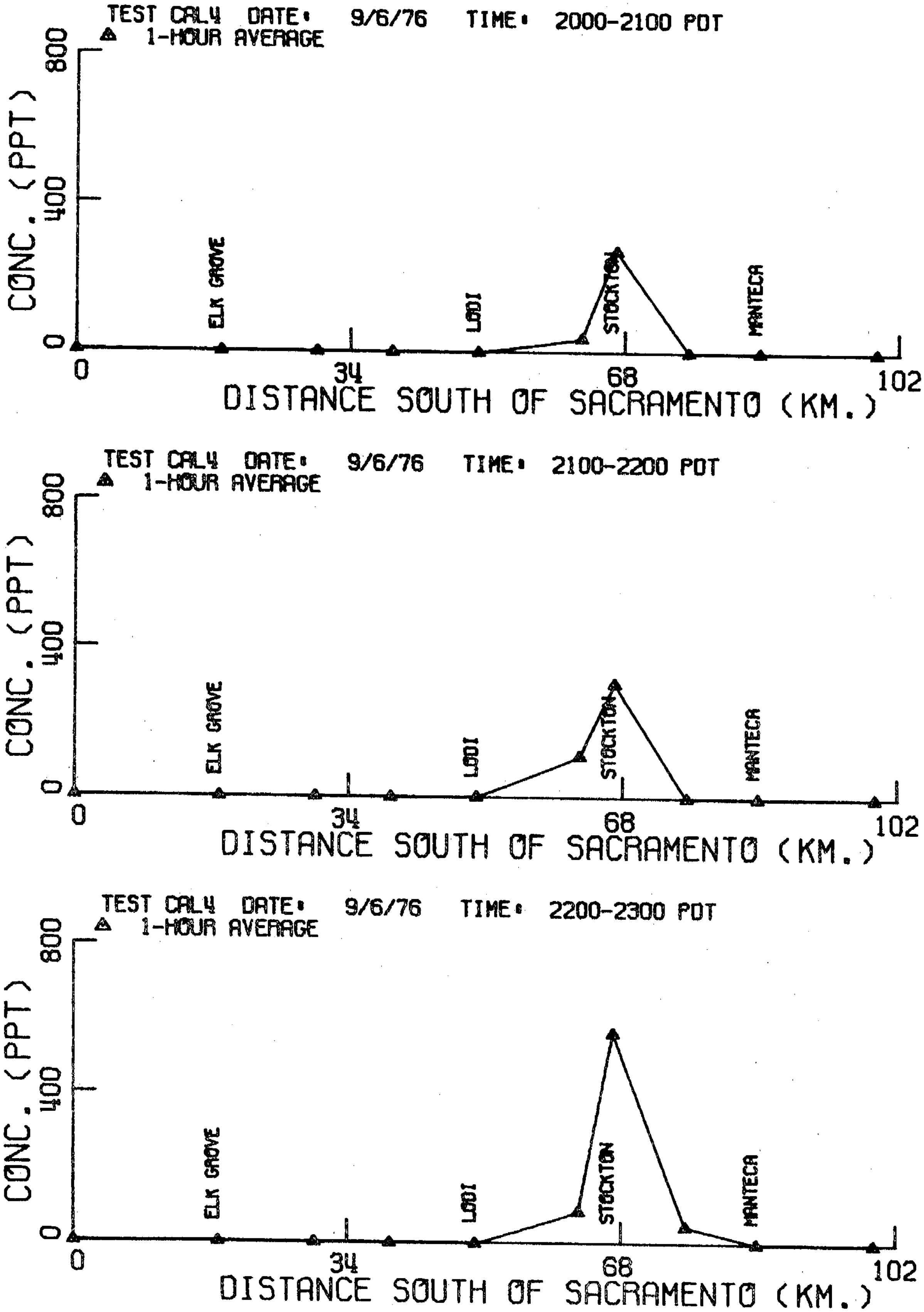


Figure 15. Hourly averaged SF_6 crosswind profiles measured along Highway 99.

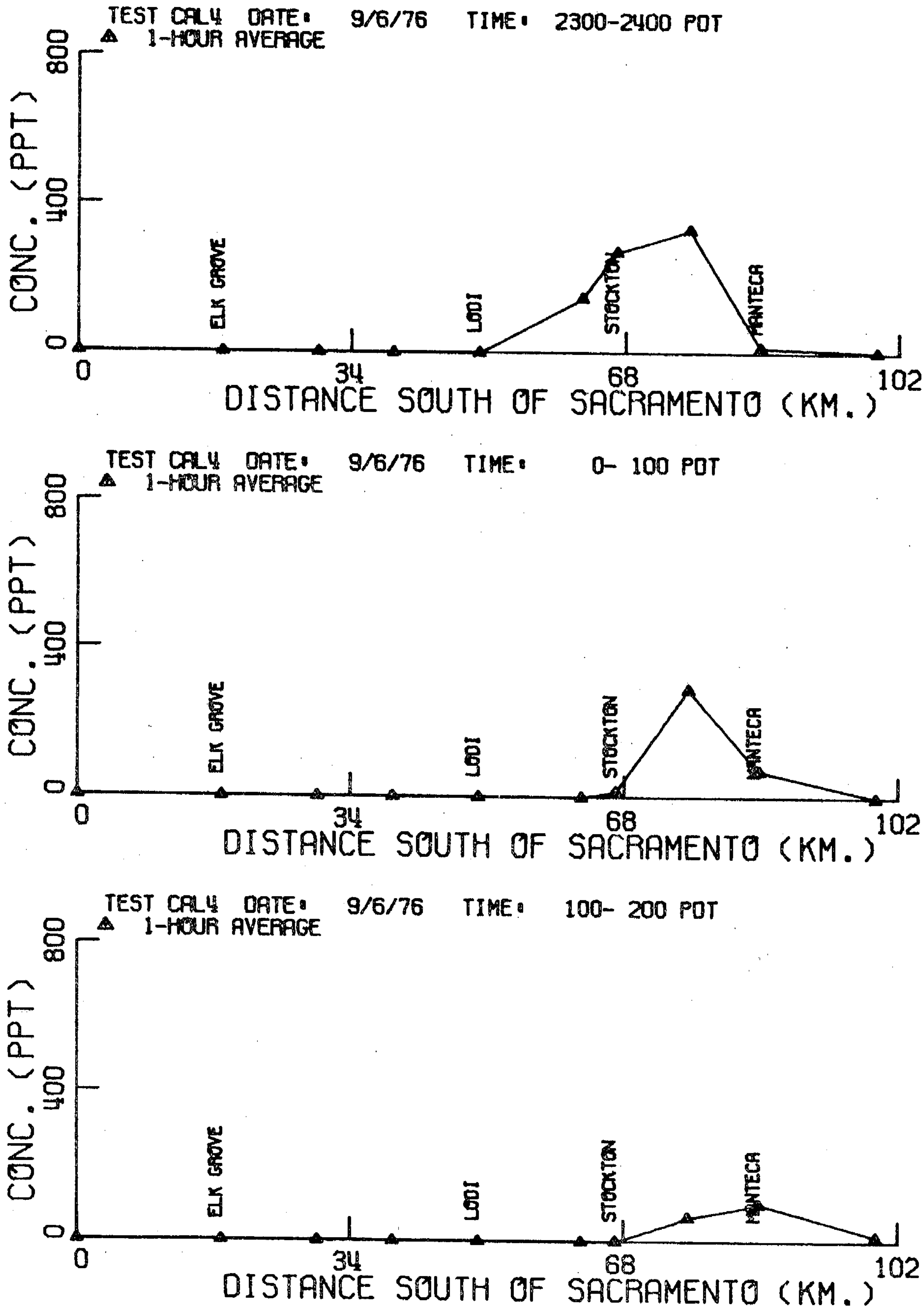


Figure 16. Hourly averaged SF_6 crosswind profiles measured along Highway 99.

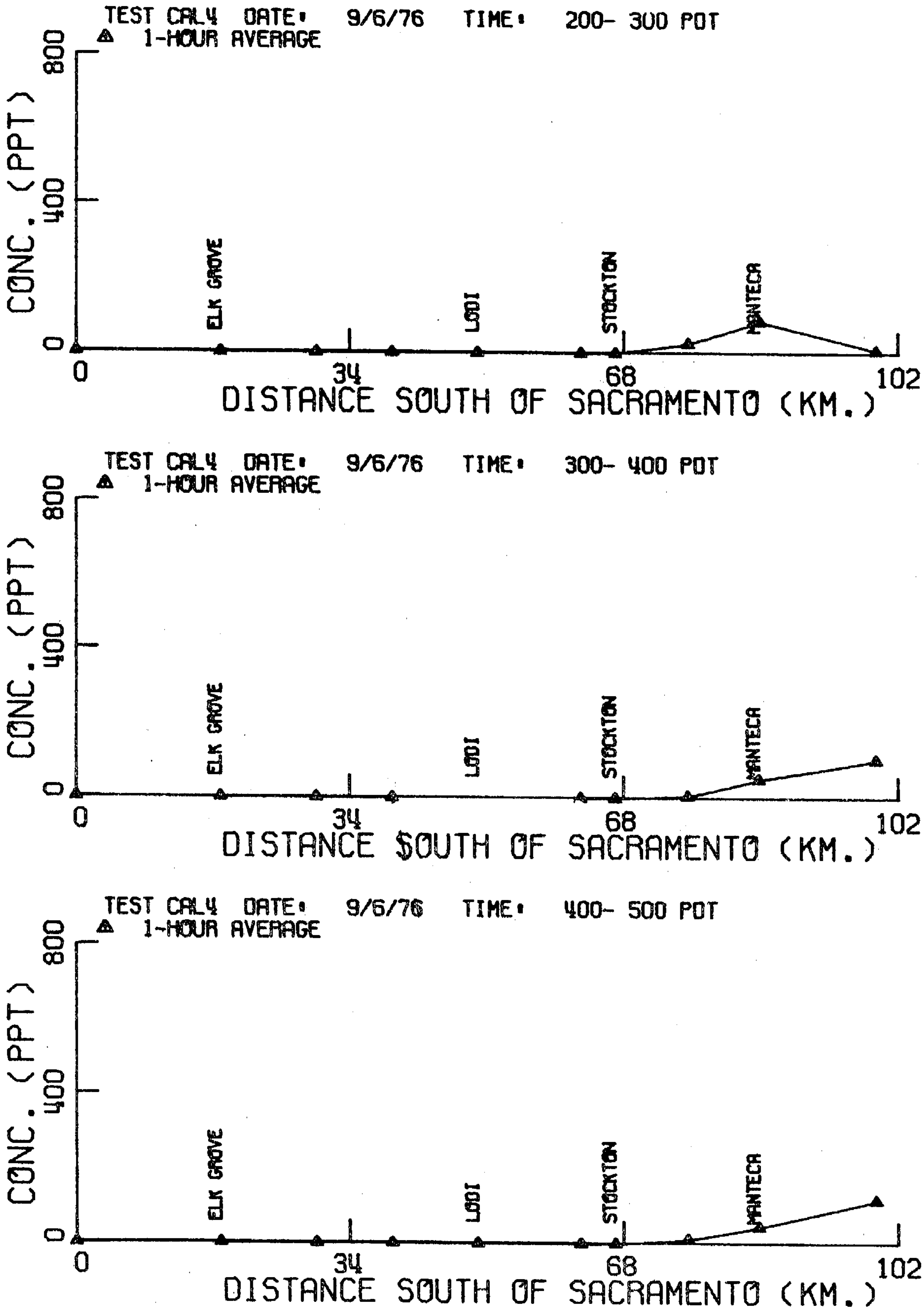
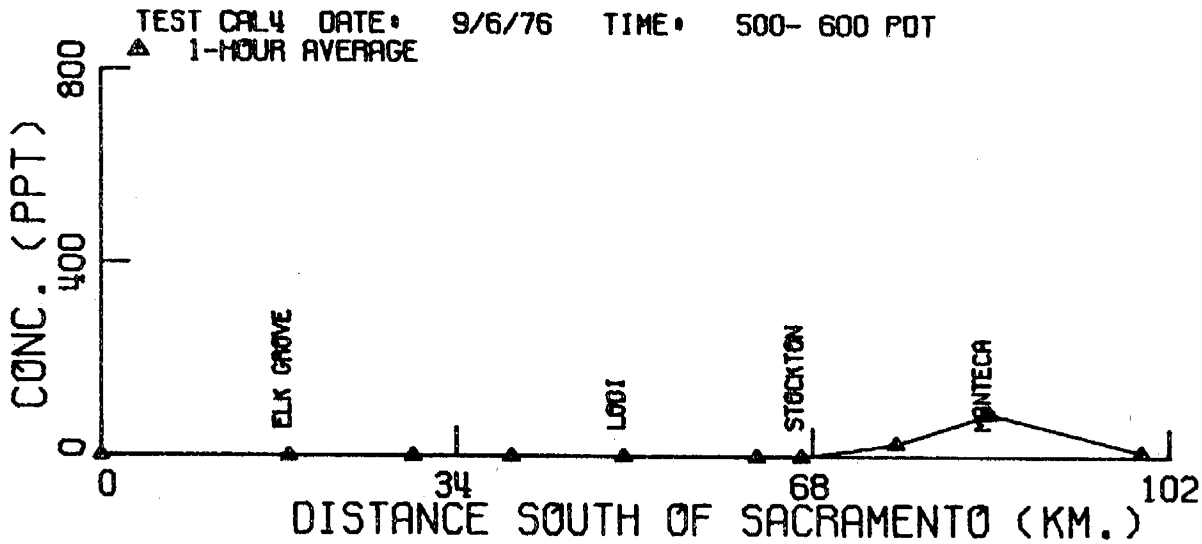
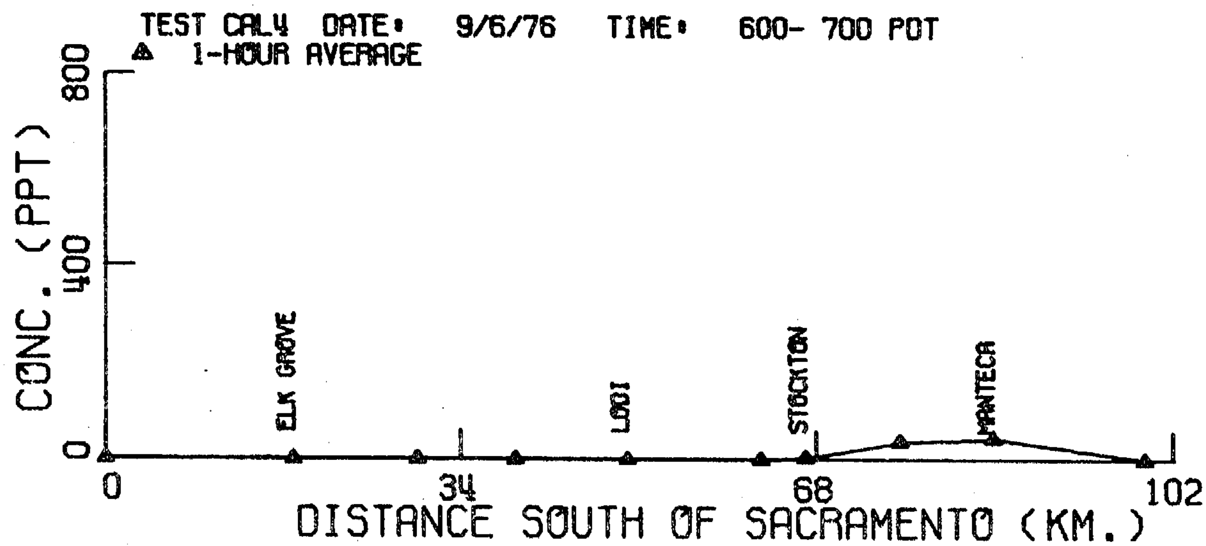


Figure 17. Hourly averaged SF_6 crosswind profiles measured along Highway 99.





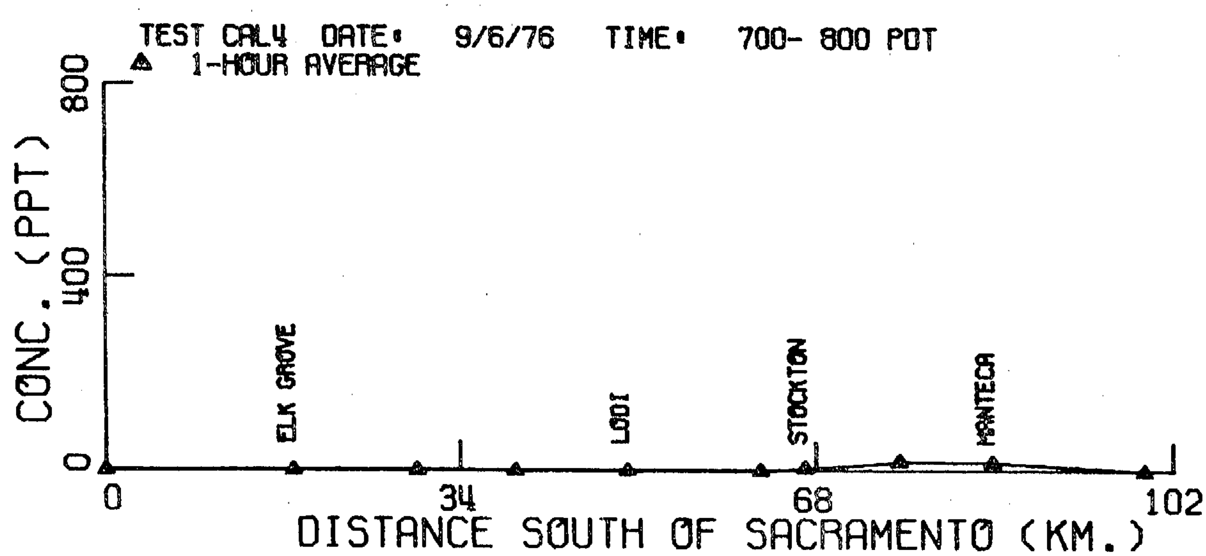


Figure 18. Hourly averaged SF_6 crosswind profiles measured along Highway 99.

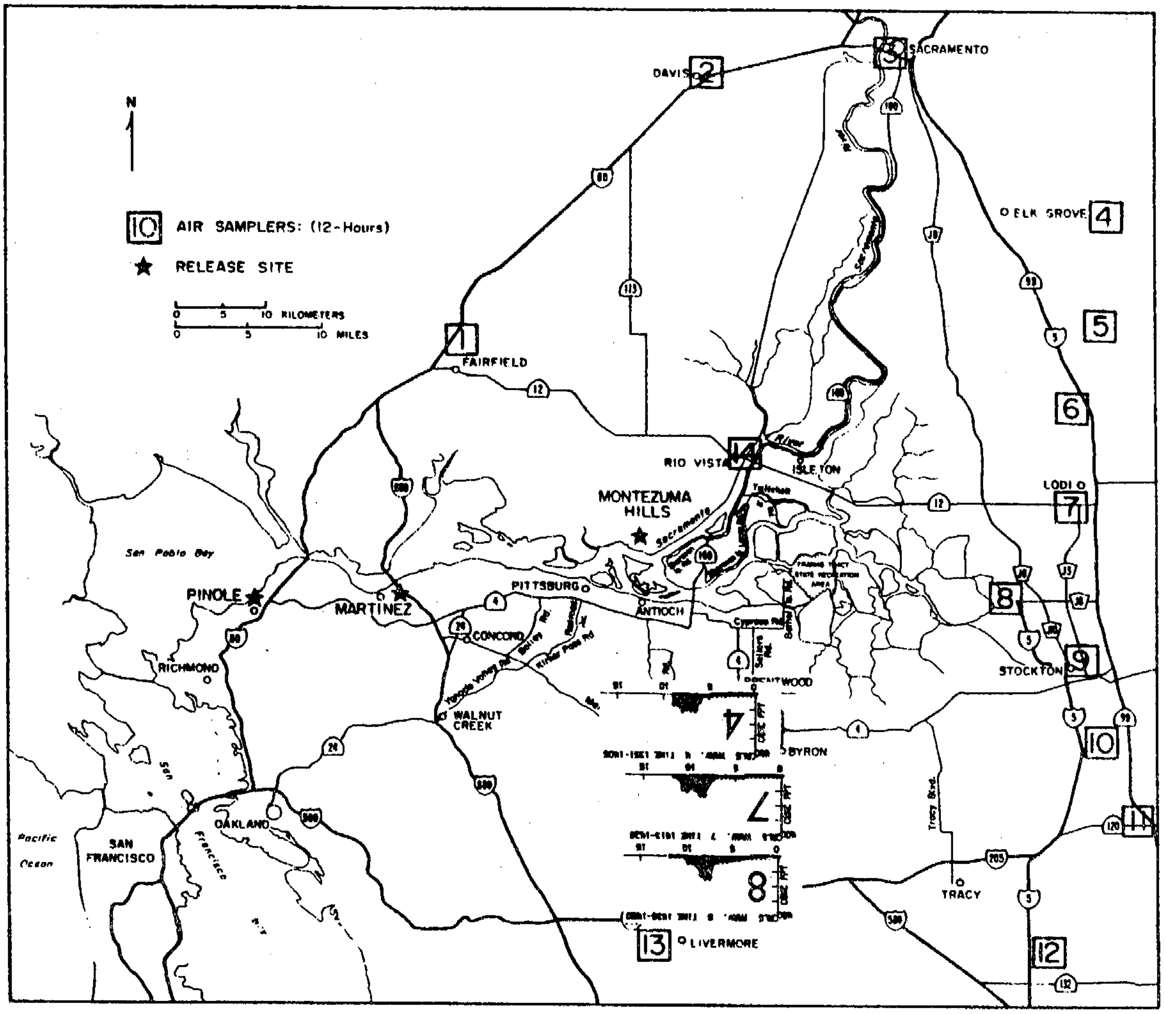


Figure 19. Overview of automobile traverse SF_6 data.

TEST 5

9/9/76

Auto Traverses: (along Balfour Road)

4 1351 - 1405 PDT, SF_6(max) = 138 ppt.

7 1413 - 1426 PDT, SF_6(max) = 141 ppt.

8 1436 - 1450 PDT, SF_6(max) = 183 ppt.

SF_6 released from the Montezuma Hills from 1130-1330 PDT.

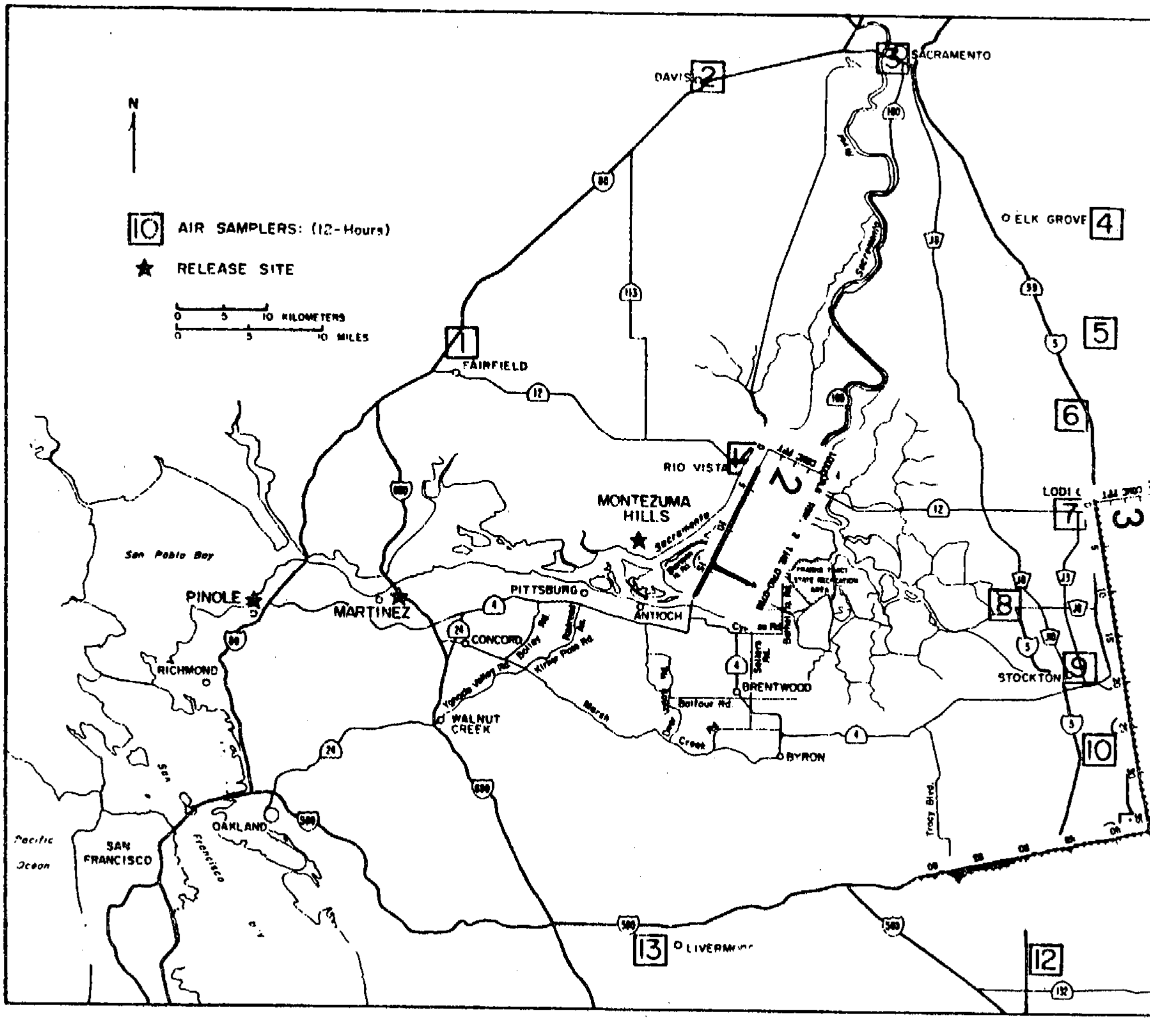


Figure 20. Overview of automobile traverse SF_6 data.

TEST 6

9/10/76

Auto Traverses:

2 0740 - 0753 PDT, SF_6(max) = 7981 ppt

3 1001 - 1051 PDT, SF_6(max) = 20 ppt

SF_6 released from the Montezuma Hills from 0600-1100 PDT.

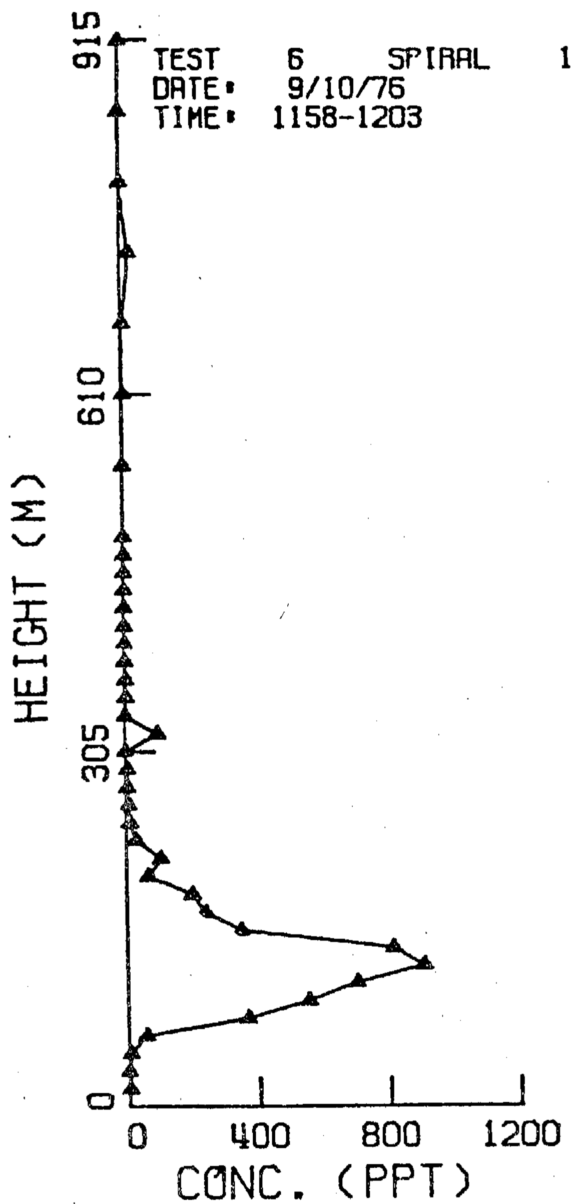


Figure 21. Vertical SF_6 profile observed over Frank's Tract Recreation Area, 20 Km downwind of the Montezuma Hills.

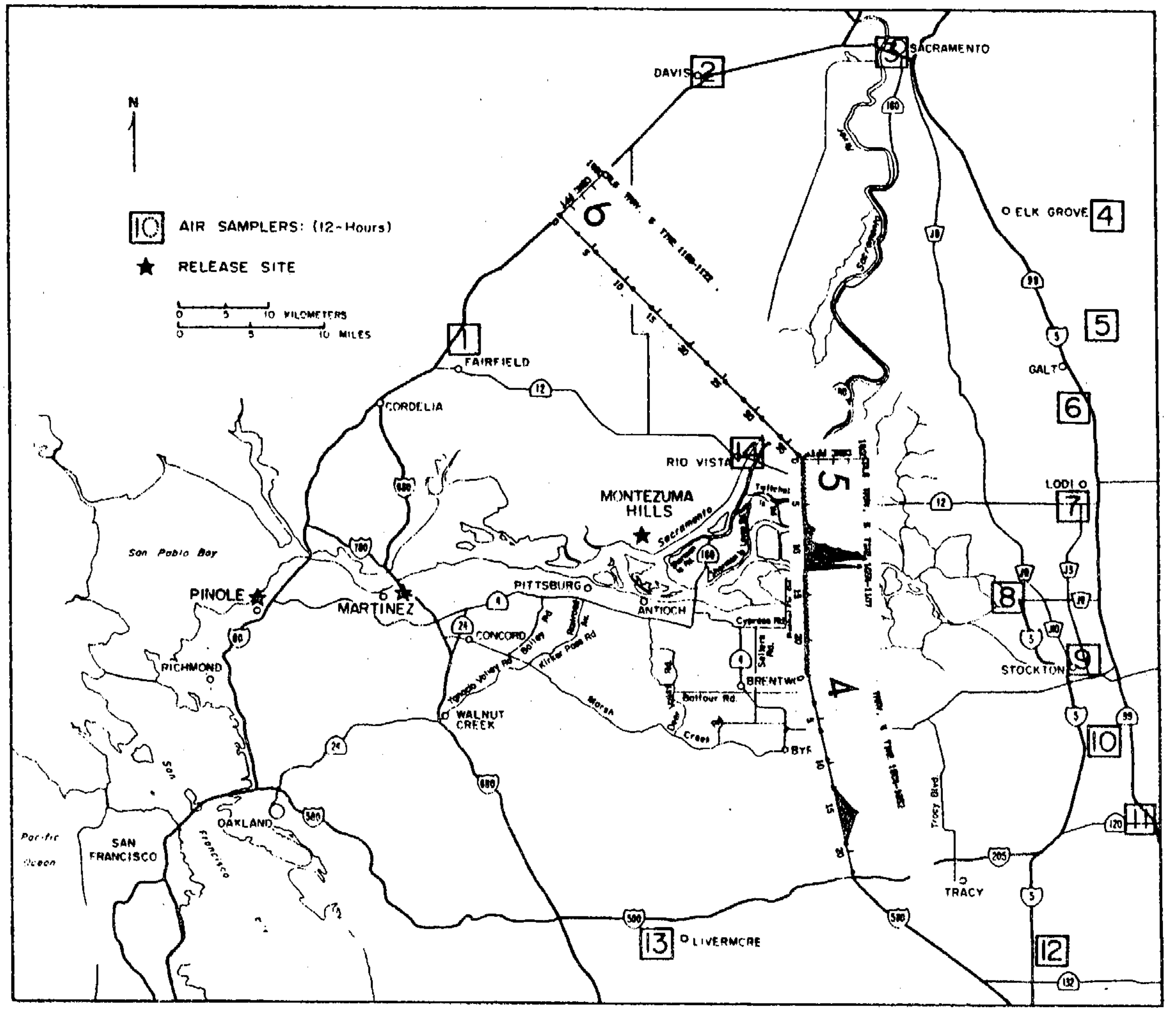


Figure 22. Overview of airborne traverse SF_6 data.

TEST 6

9/10/76

Airborne Traverses:

4 1044 - 1052 PDT, 183 m, SF_6(max) = 396 ppt

5 1054 - 1107 PDT, 183 m, SF_6(max) = 1387 ppt

6 1109 - 1122 PDT, 183 m, SF_6(max) = 0 ppt

SF_6 released from the Montezuma Hills from 0600-1100 PDT.

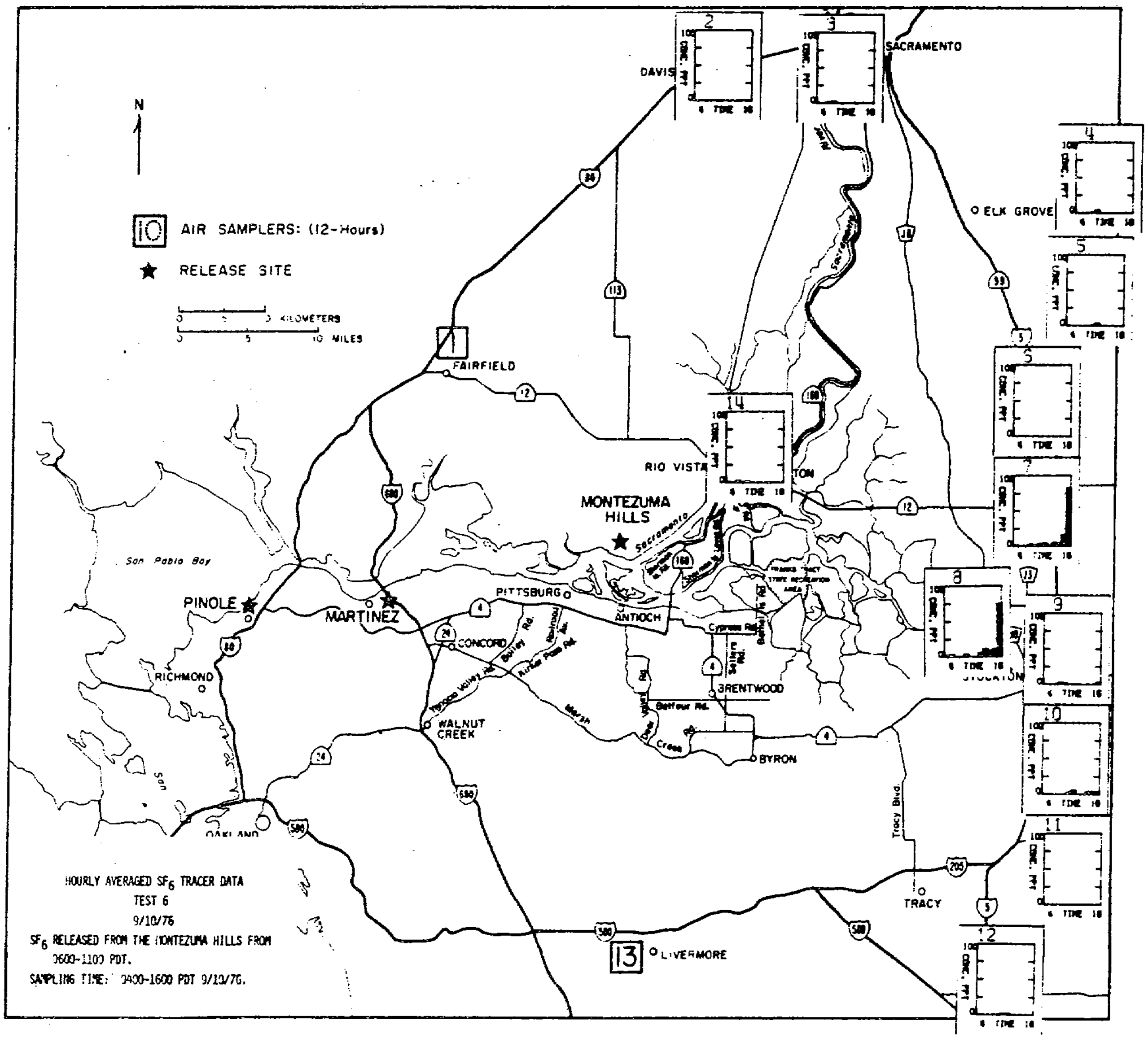


Figure 23. Overview of hourly averaged SF_6 data. Full scale SF_6 = 100 ppt.

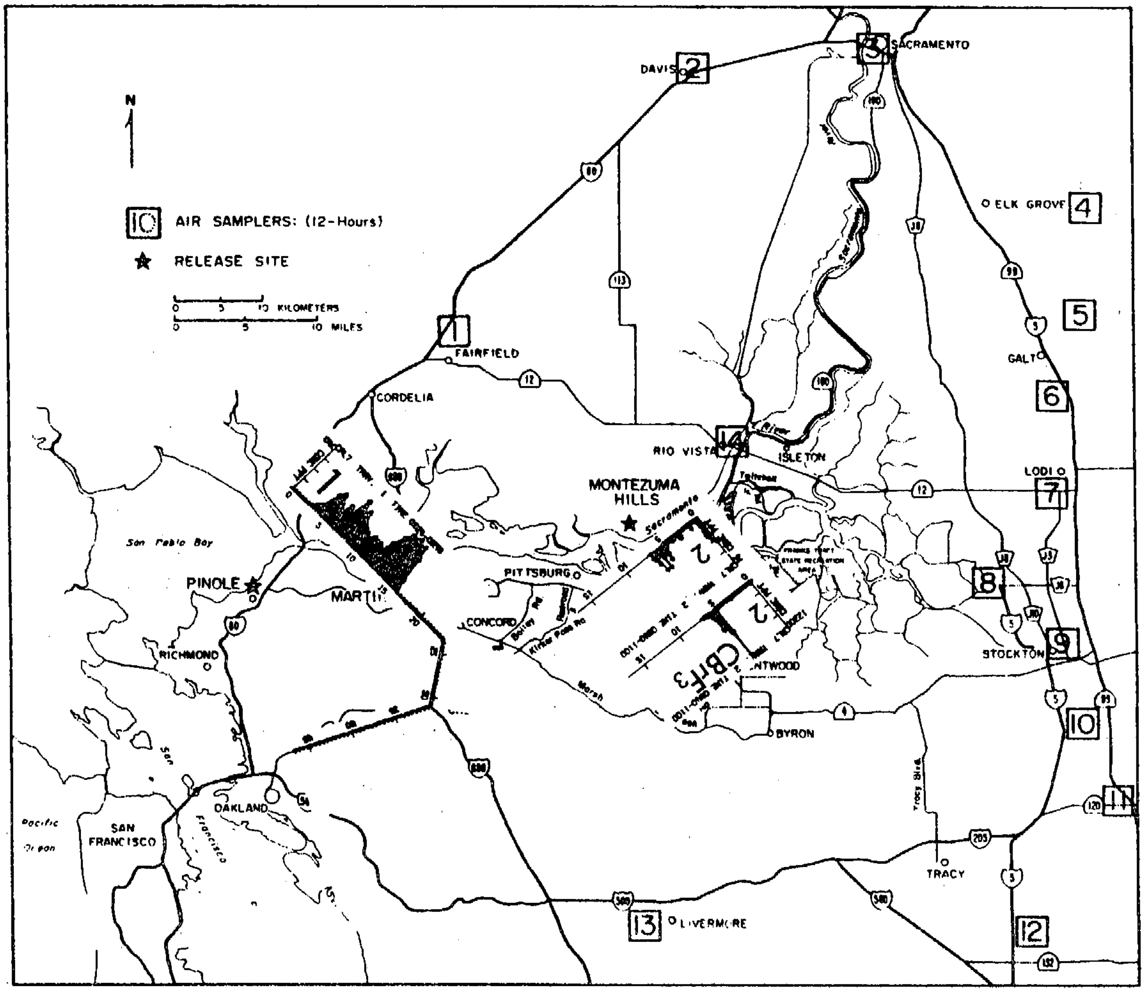


Figure 24. Overview of automobile traverse SF_6 and $CBrF_3$ data.

TEST 7

9/13/76

Auto Traverses:

1 0924-0925 PDT, SF_6(max) = 614 ppt.

2 0940-1100 PDT, SF_6(max) = 11 ppt.

0940-1100 PDT, $CBrF_3$(max) = 12,140 ppt.

SF_6 released from Pinole from 0600-1500 PDT.

$CBrF_3$ released from the Montezuma Hills from 0900-1100 PDT, and from 1300-1400 PDT.

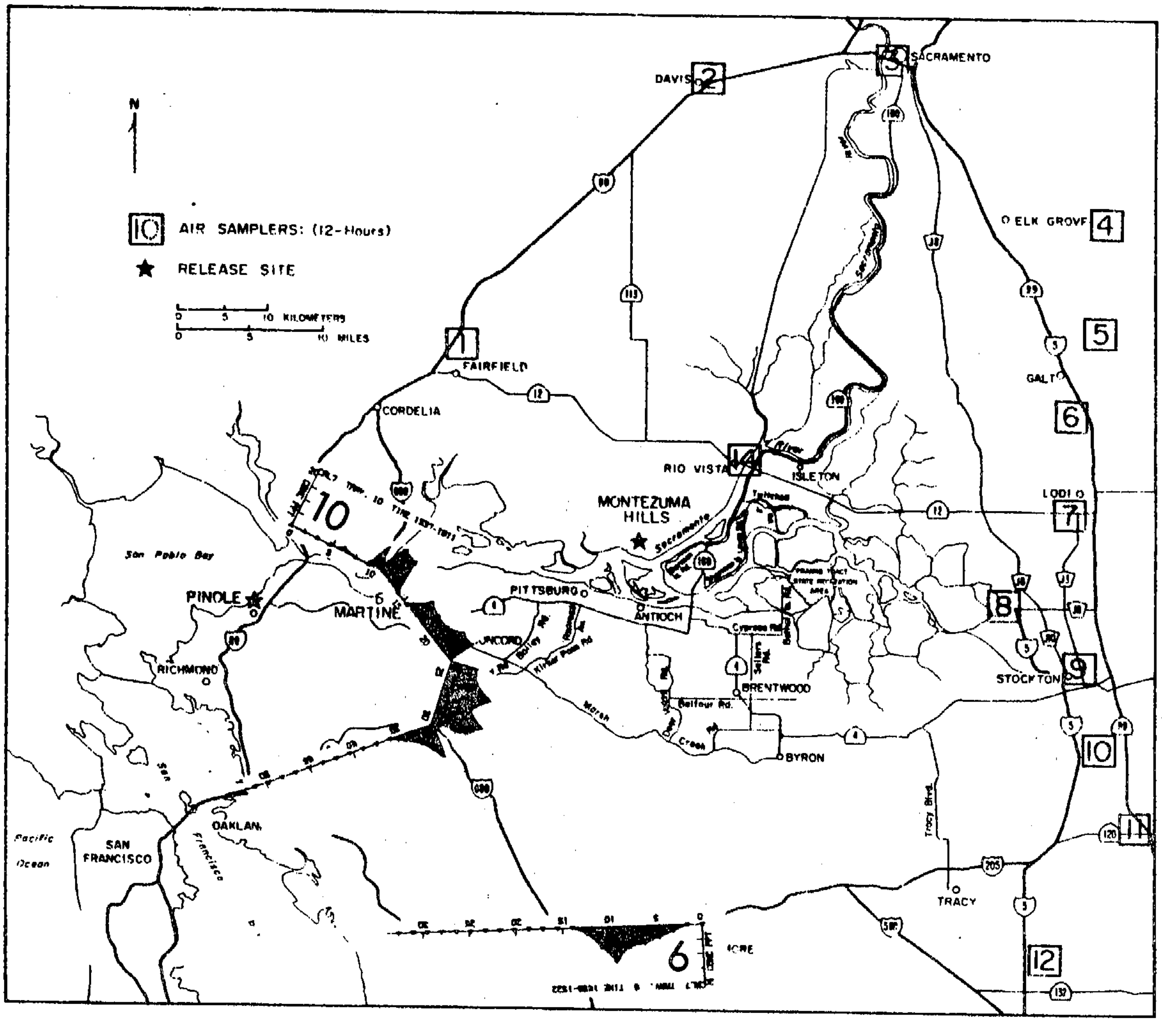


Figure 25. Overview of automobile traverse SF_6 data.

TEST 7

9/13/76

Auto Traverses:

9 1458 - 1522 PDT, SF_6(max) = 12 ppt.

10 1537 - 1611 PDT, SF_6(max) = 16 ppt.

SF_6 released from Pinole from 0600-1500 PDT.

$CBrF_3$ released from the Montezuma Hills from 0900-1100 PDT and from 1300-1400 PDT.

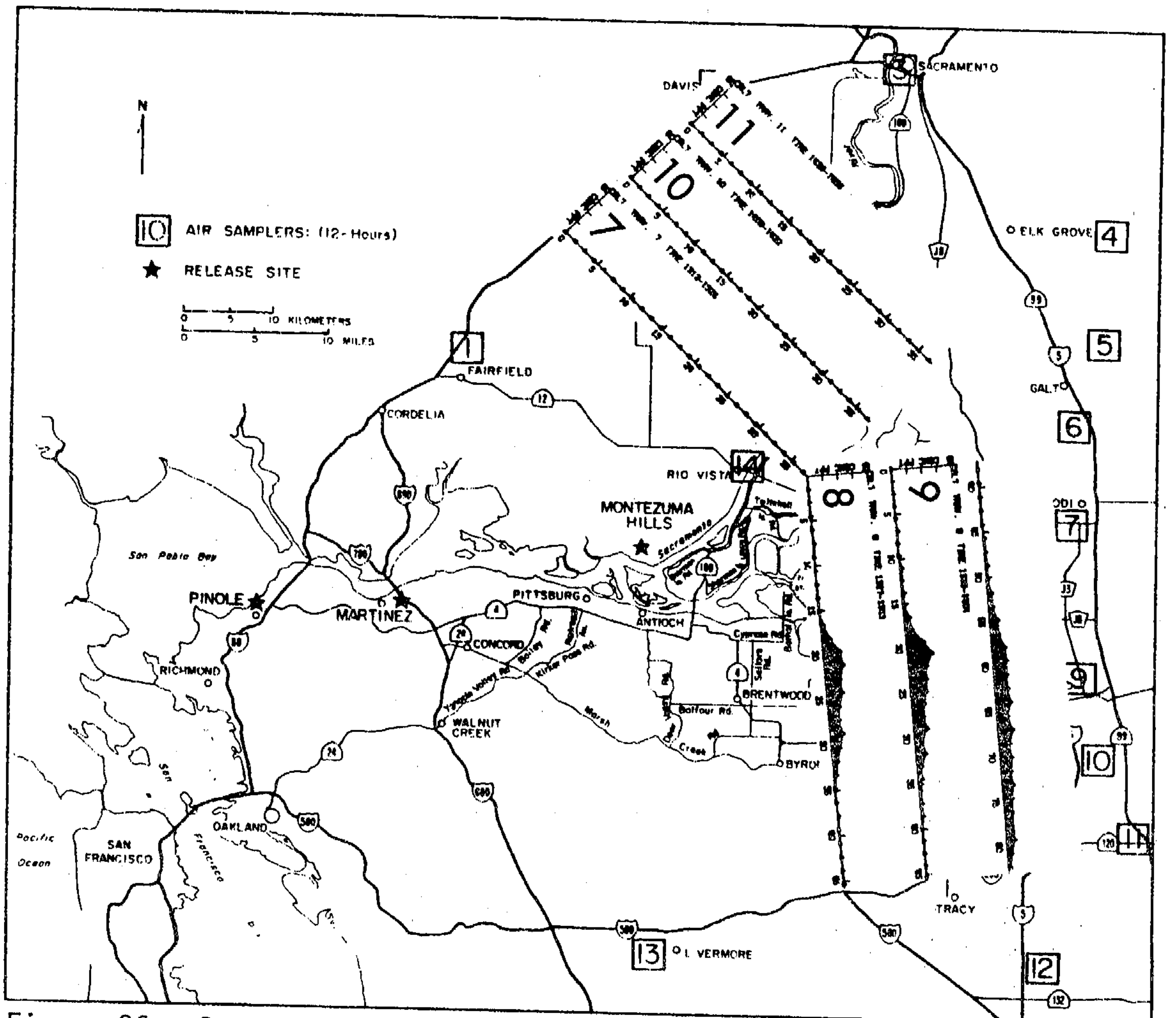


Figure 26. Overview of airborne traverse SF_6 data measured at three altitudes between Vacaville, Iselton, and the I580-I205 junction.

TEST 7

9/13/76

Airborne Traverses:

7 1312-1324 PDT, 183 m, SF_6(max) = 0 ppt.
8 1327-1343 PDT, 183 m, SF_6(max) = 19 ppt.
9 1348-1408 PDT, 305 m, SF_6(max) = 25 ppt.
10 1409-1422 PDT, 305 m, SF_6(max) = 1 ppt.
11 1428-1456 PDT, 427 m, SF_6(max) = 15 ppt.

SF_6 released from Pinole from 0600-1500 PDT.

$CBrF_3$ released from the Montezuma Hills from 0900-1100 PDT and from 1300-1400 PDT.

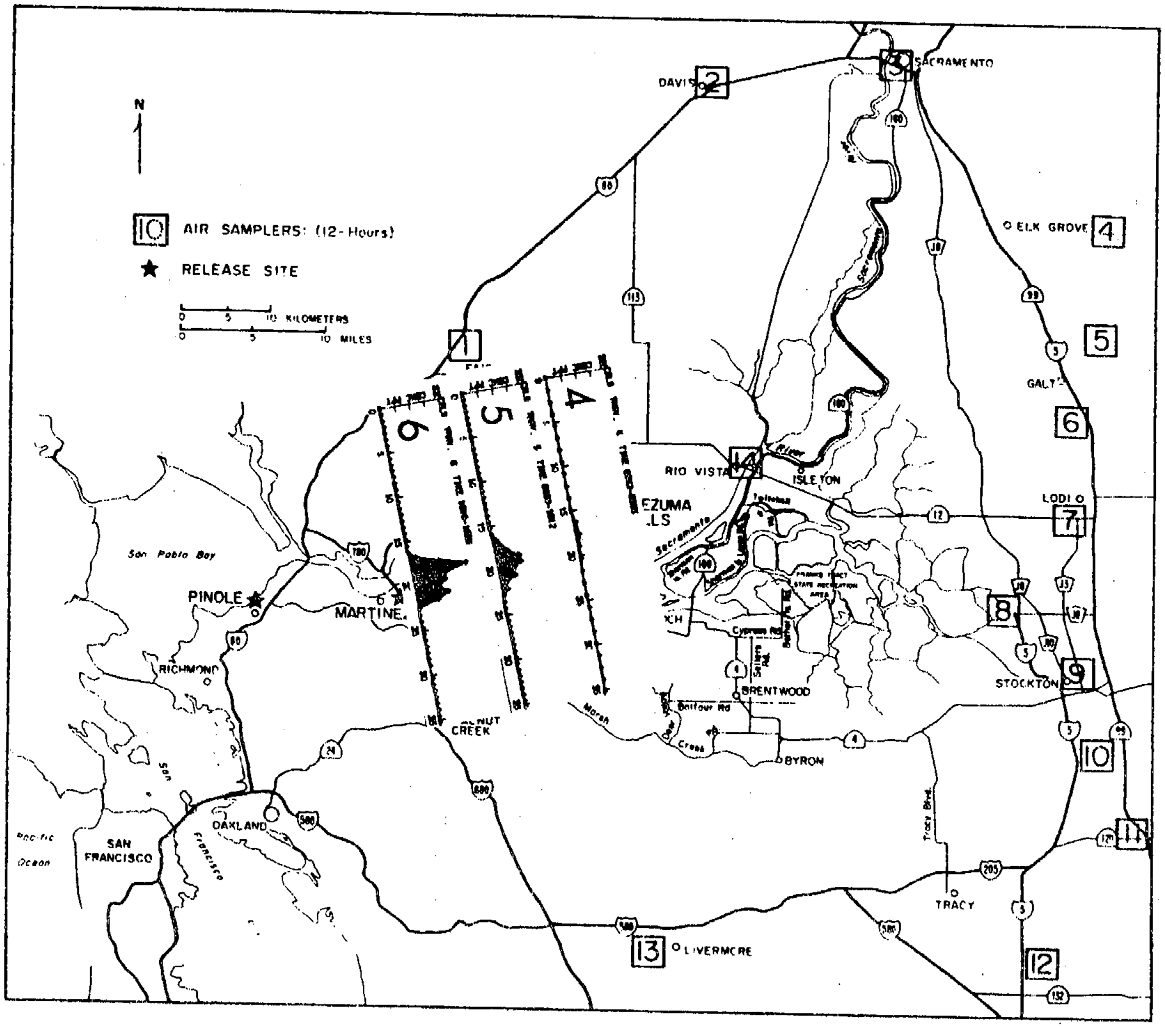


Figure 27. Overview of airborne traverse SF_6 data measured at three altitudes between Cordelia and Walnut Creek.

TEST 8

9/14/76

Airborne Traverses:

4 0942-0955 PDT, 427 m, SF_6(max) = 22 ppt.

5 0959-1012 PDT, 305 m, SF_6(max) = 134 ppt.

6 1016-1028 PDT, 183 m, SF_6(max) = 304 ppt.

SF_6 released from Pinole from 0730-1300 PDT.

5. Summary of Results, Conclusions, and Recommendations

1. Mass balances were performed with the automobile and airborne traverse data. The accuracy of these analyses depended upon the accuracy with which the vertical profiles of the tracer concentration and wind speed could be determined. In cases where no airborne data were available and the tracer plume could not be assumed to be vertically well-mixed (i.e., under stable evening and nighttime conditions), as expected, the mass balances widely overestimated the percent tracer observed in a traverse. However, excluding the stable cases, the overall average percent tracer observed in 43 crosswind traverses was 95%. Hence, essentially all of the tracer was accounted for by the airborne and automobile traverse data.

2. Due to the steadiness of the winds, the plume trajectories at 10 km downwind of the Montezuma Hills were found to be quite similar from test to test. Although the lateral dispersion decreased with increasing atmospheric stability, the plume centerline was found to pass over Highway 160 within a crosswind zone of 2.1 km (Figure 28).

A similar analysis of the data obtained along Highway 99, 50 km downwind, indicated that the average position of the plume centerlines was 5 km south of Stockton; the standard deviation associated with the average position was ±14 km (Figure 29). A straight line can be drawn from the release point in the Montezuma Hills to the average

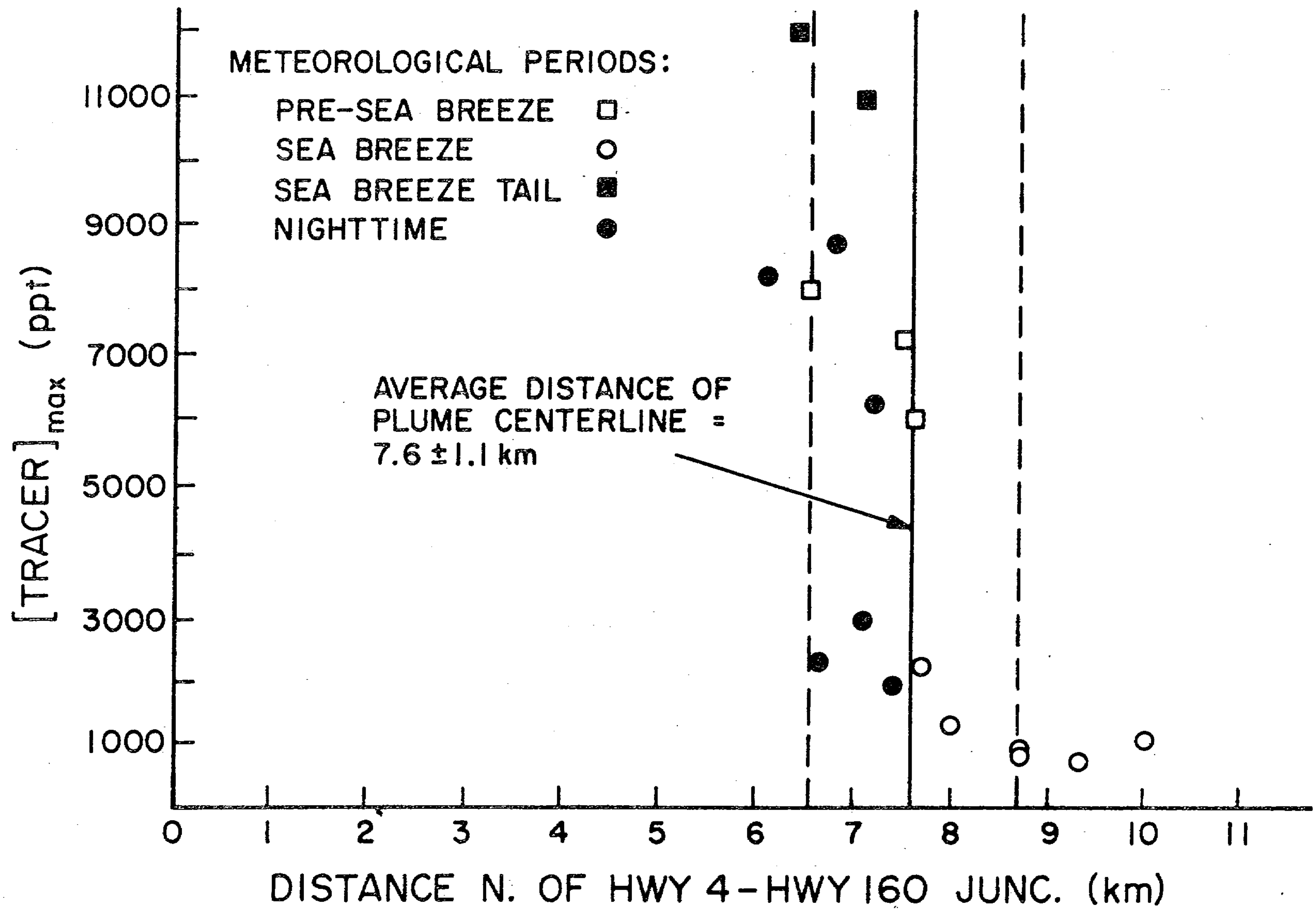


Figure 28. Plume centerline concentration as a function of distance north of the Highway 4 - Highway 160 junction taken from automobile traverse data for Dow tracer releases.

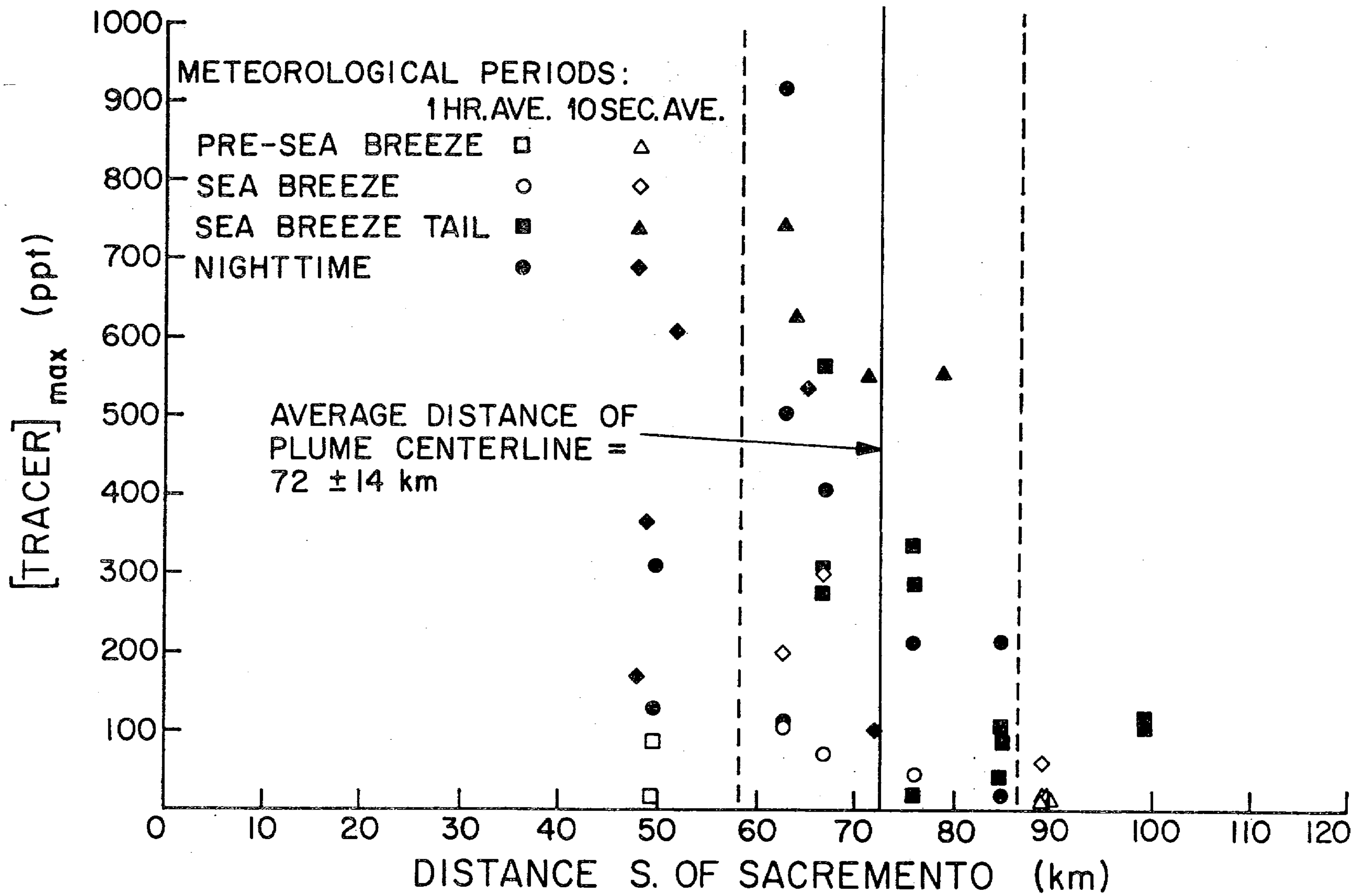


Figure 29. Plume centerline concentration as a function of the distance south of Sacramento along Highway 99 taken from automobile and hourly averaged crosswind tracer profiles.

centerline position of the plume crossing Highway 160. The extension of this line intersects Highway 99 approximately 2 km north of the observed centerline position. The average plume centerlines from the Dow site to Highway 160 and from Highway 160 to Highway 99 and the standard deviations associated with the centerline locations are shown in Figure 30. On the average, plumes emitted from the Montezuma Hills during the test periods were transported southeast directly over Stockton.

3. The commonly used Hino correction (1968) was found to grossly underestimate the hourly averaged tracer concentrations computed from 10-second averaged concentrations. The Hino relation suggested that $C_{HR}/C_{10s} = 0.18$ where C_{HR} is the hourly averaged centerline concentration and C_{10s} is the 10-second averaged centerline concentration. However, actual measurements in the Delta region indicated that $C_{HR}/C_{10s} = 0.7$.

4. The horizontal dispersion parameter, σ_y, was calculated for each crosswind traverse; the direction of the wind was taken into account in these calculations. These values were used to compare the rates of dispersion with those based upon Pasquill stability classes as indicated by Turner (1970). The comparison indicated that atmospheric stability generally decreases with increasing distance downwind from the Montezuma Hills. The results of the dispersion analysis for the releases from the Montezuma Hills are summarized in Figure 31. It appears that during the afternoon the heating of the land decreases atmospheric stability and dominates the stabilizing effects of the jet of air passing over the Montezuma

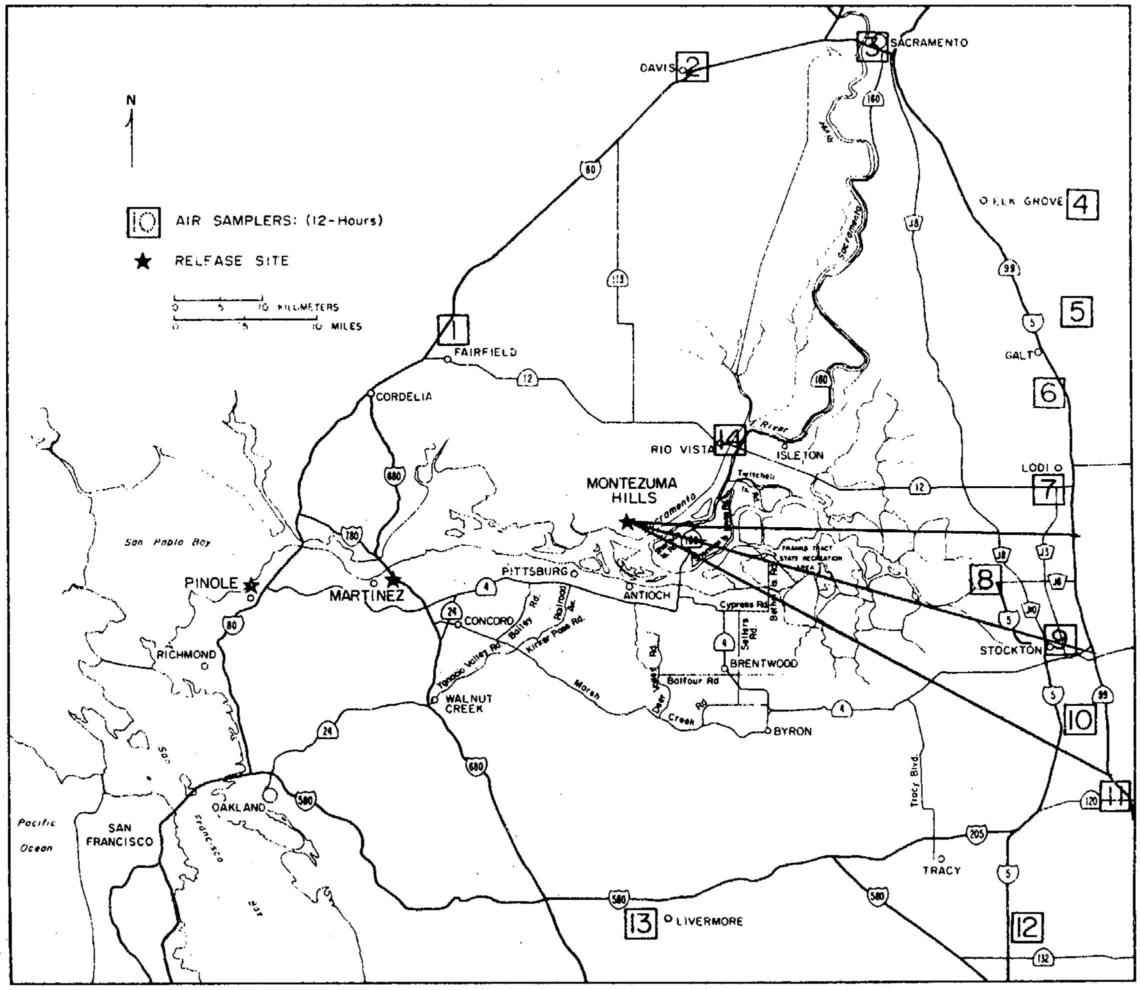


Figure 30. Average plume centerline locations for plumes emitted from the Dow site in the Montezuma Hills. The outside lines represent the standard deviations associated with the average centerline locations.

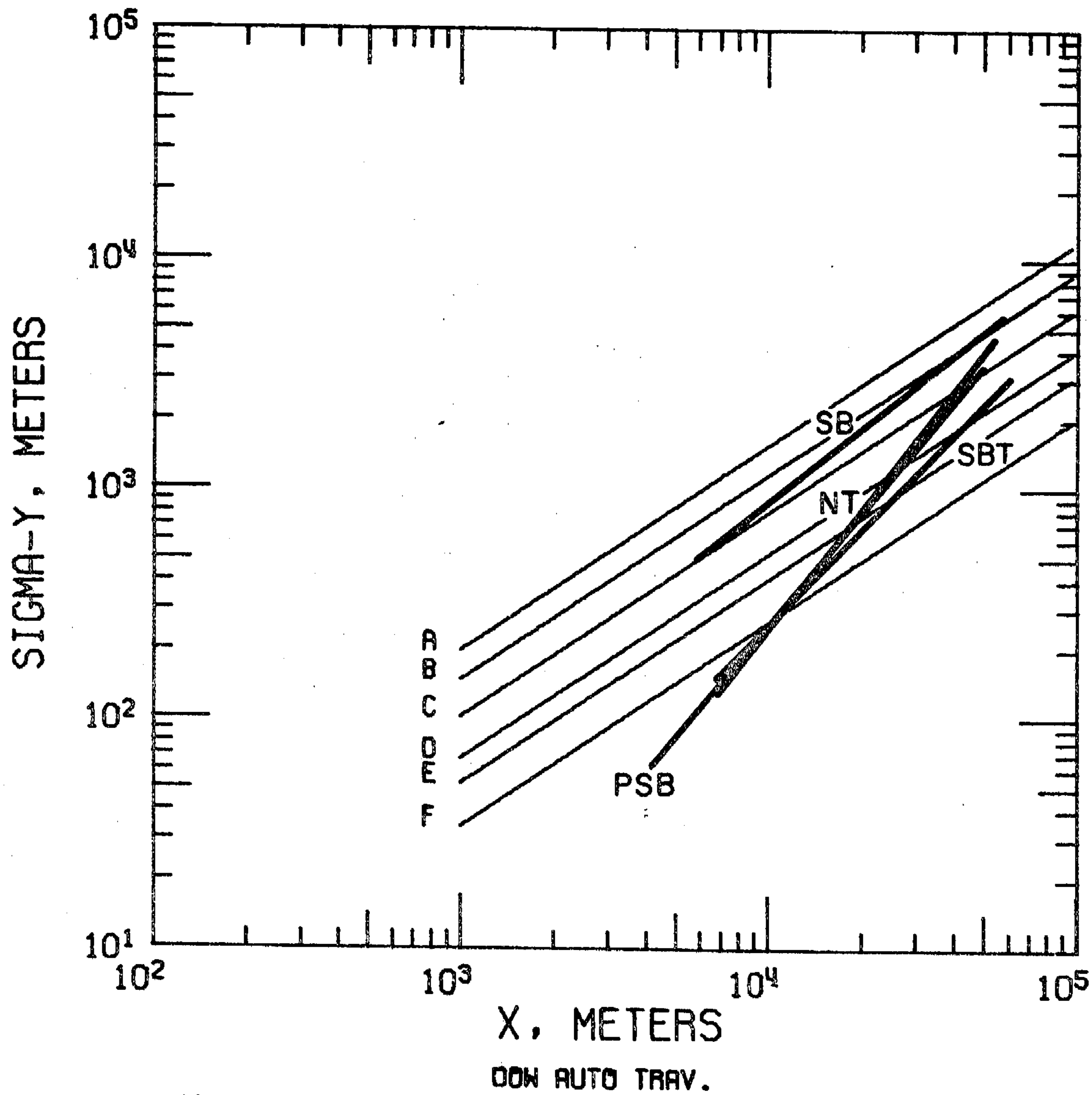


Figure 31. Horizontal crosswind dispersion parameter, σ_y, as a function of distance downwind of the Dow site during Pre-Sea Breeze (PSB), Sea Breeze (SB), Sea Breeze Tail (SBT), and Nighttime (NT) conditions, and the horizontal dispersion parameter associated with Pasquill atmospheric stability classes.

Hills. At other times, the steadiness of the winds causes horizontal dispersion (at short distances downwind of the release) to be less than that predicted. The horizontal dispersion of plumes emitted from Pinole and Martinez during the Pre-Sea Breeze and Sea Breeze periods was found to be similar to that associated with plumes emitted from the Montezuma Hills during the Sea Breeze period.

5. Vertical dispersion parameters, estimated from surface traverses using mass balance arguments, were found to be similar in value to those suggested by Pasquill. However, as shown in Figure 32 for releases from the Montezuma Hills under nighttime conditions, vertical dispersion was relatively constant from 7 to 50 km downwind.

6. Estimation of tracer concentrations using the Gaussian plume model were found to be reasonably accurate. For short distances downwind of the release, calculations based upon experimental values of σ_y σ_z were in closer agreement with observed concentrations than those based upon the Pasquill values of σ_y and σ_z. Typical results of this analysis are shown in Figure 33 for Test 1. Calculations, based upon the Gaussian plume model, indicate that after a characteristic distance downwind of the release, realistic variations of the effective stack height do not significantly influence ground-level concentrations. The tracer data indicate that this characteristic distance is less than about 10 km during the day. However, at night, due to a decrease in the extent of vertical mixing which occurs, this characteristic distance may increase. For example, under stability class E, an effective stack

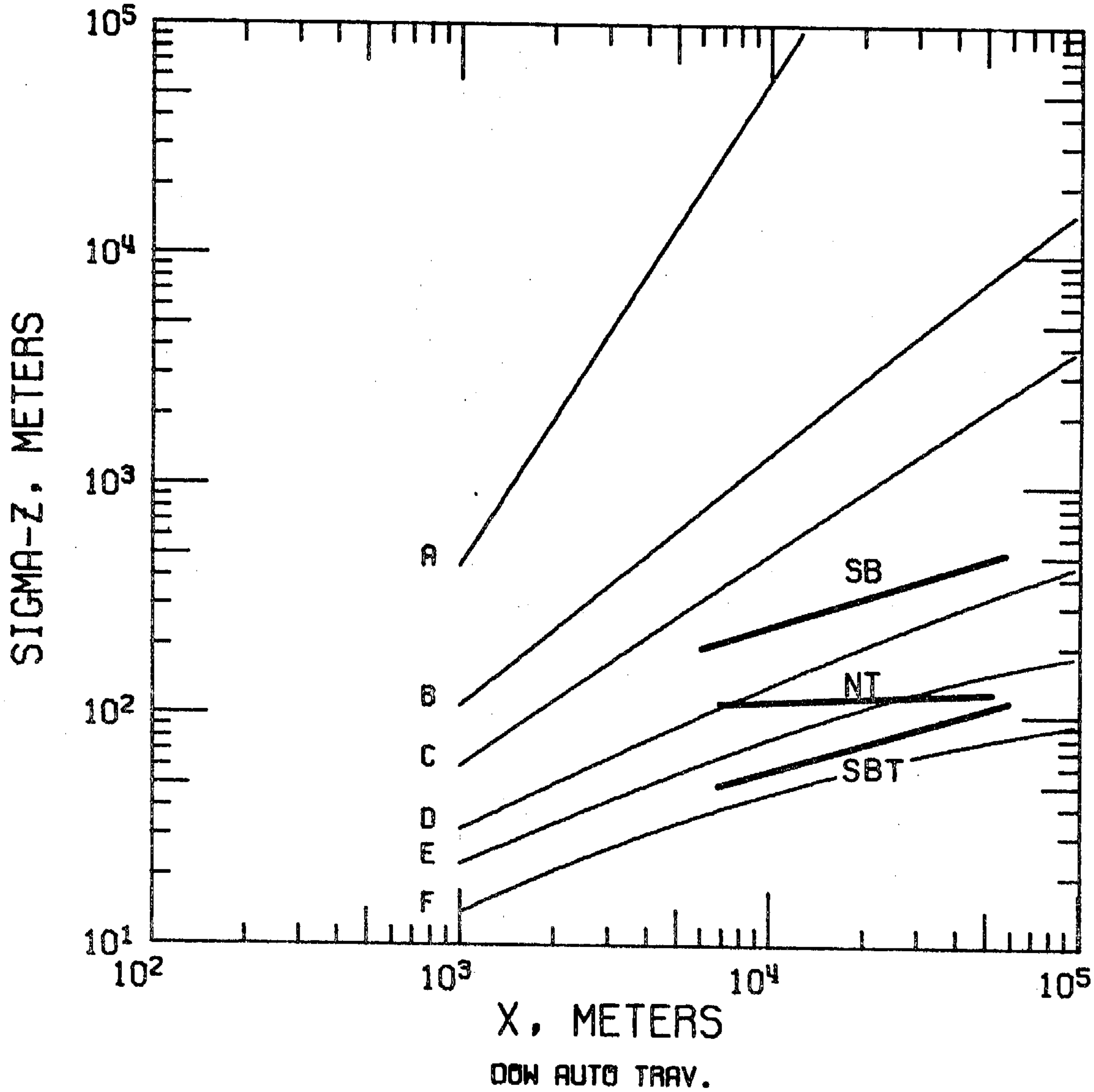


Figure 32. Vertical crosswind dispersion parameter, σ_z, as a function of distance downwind of the Dow site during Sea Breeze (SB), Sea Breeze Tail (SBT), and Nighttime (NT) conditions, and the vertical dispersion parameter associated with Pasquill atmospheric stability classes.

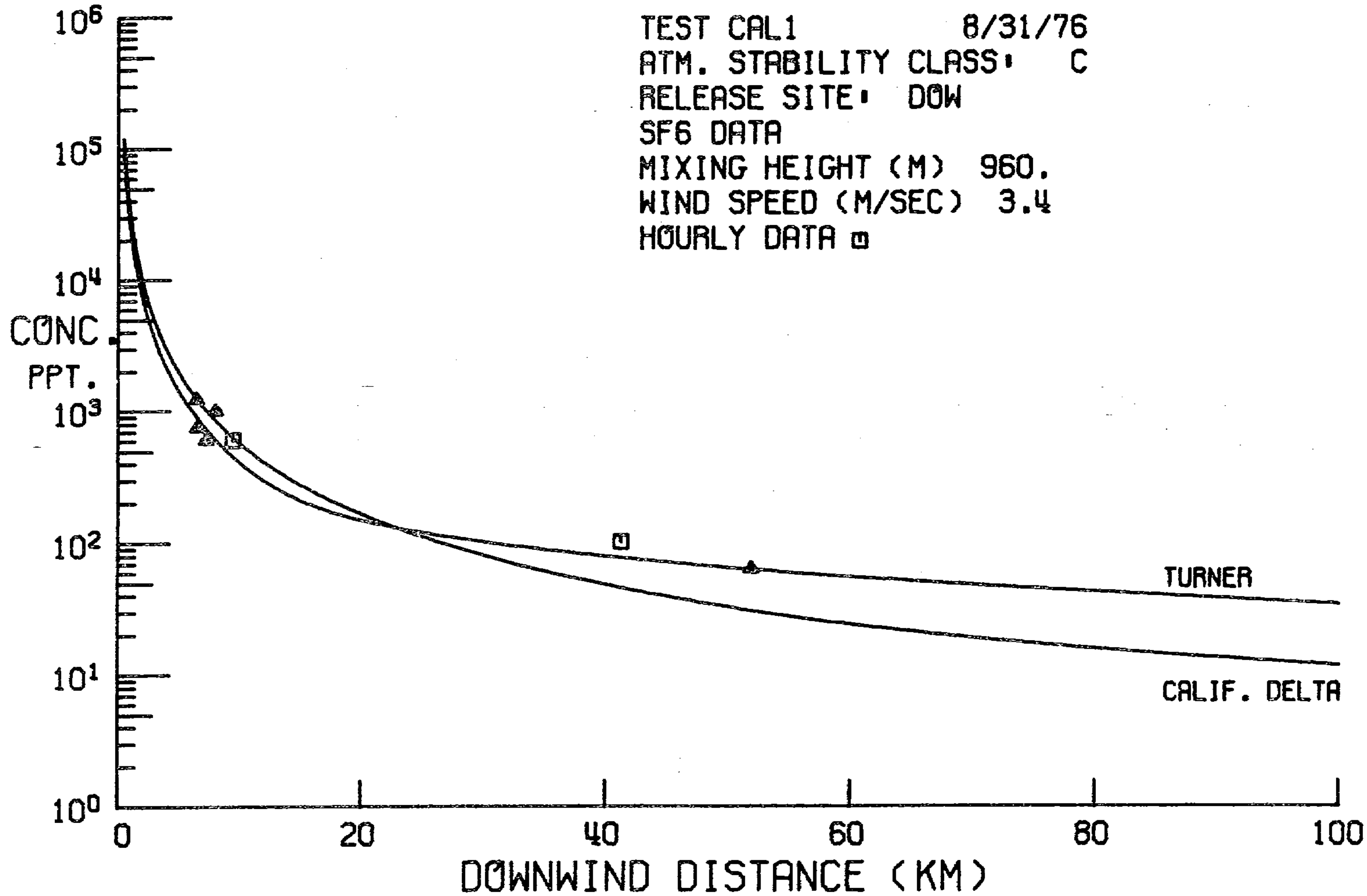


Figure 33. Centerline tracer concentrations compared with centerline concentrations predicted using the Gaussian plume model. The "Turner" curve is based upon values of σ_y and σ_z given by Pasquill in Turner (1970); the "Calif. Delta" curve is based upon the corresponding experimental values. Values of the meteorological variables represent regional averages during the test.

height of 107 meters yields ground-level concentrations less than half those from a ground-level release for distances up to 20 km downwind.

7. A nomograph was developed to permit rapid calculation of pollutant concentrations from tracer data and pollutant emission rates. The conversion of concentrations implies that either the pollutant is essentially unreactive or that it reacts so rapidly that its product disperses like the tracer. A nomograph based upon the average SF_6 release rate during the field study is shown in Figure 34. Examples illustrating the conversion of 100 ppt SF_6 to various pollutant concentrations are also shown. These examples are based upon projected emissions from the Dow Chemical plant in the Montezuma Hills. Dow emission rates for NO_x (NO_2) SO_2, and CO were estimated to equal 9.4, 1.1, and 1.0 tons/day, respectively (Moyer, 1977); detailed emission data are given in Volume II.

8. The tracer data along with the projected emission rates indicate that the air quality standards for CO and SO_2 are not likely to be violated. However, if the conversion of NO to NO_2 is rapid, the air quality standard for NO_2 might be exceeded. The most probable times for such an occurrence are during the Sea Breeze Tail and Nighttime conditions; the downwind distance to which the NO_2 standard is likely to be exceeded is estimated to be about 10 km (Table 2). The impact of NO emissions upon the formation of ozone was not considered. However, the tracer data can be used in model calculations to complete a full impact study.

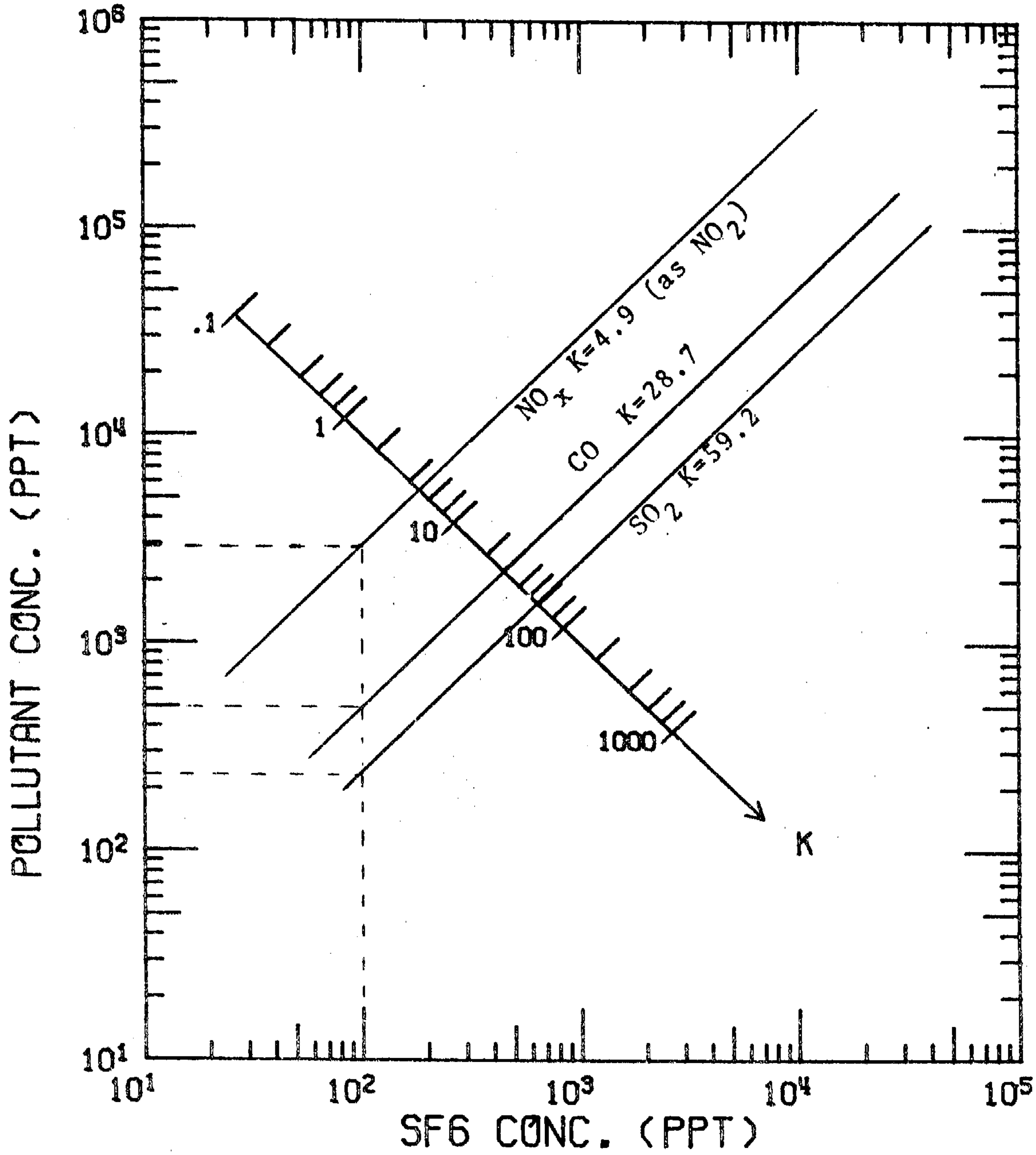


Figure 34. Conversion nomograph for converting SF_6 tracer concentrations measured during the field study to pollutant concentrations. K = (pollutant molecular wt., grams) / (pollutant emission rate, tons/day). Values of K shown above are based on projected pollutant emissions from the Montezuma Hills Dow chemical complex. Dashed line indicates the corresponding tracer-to-pollutant concentration conversions.

TABLE 2.

COMPARISON OF NO_2 CONCENTRATION MEASUREMENTS AND PREDICTIONS

$[NO_2]_{max}$ ppb

Test	Ambient Measurements[1] Montezuma Hills	Stockton	Estimated from Tracer Data[2] (hourly average) 10 Km	50 Km	Predicted by Dow[3]	Predicted Using Tracer Dispersion Data[4] 10 Km	50 Km
1	50	70	18	3.0	5.8 at 10 Km from tracer release	12	0.7
2	60	80	46	-		81	2
3	40	70	(200)	30		105	6
4	50	60	(242)	16		250	17
5	70	-	(16)	-		9	1
6	70	80	(199)				
7	10	60	(167)	-		-	2
8	40	60	-	-		-	-

[1] Ambient hourly averaged concentrations collected by Rockwell at Montezuma Hills and the San Joaquin APCD at Stockton during the test period.

[2] NO_2 concentrations estimated using maximum observed hourly-averaged tracer concentrations and projected Dow emission rates. Values in parentheses are hourly values estimated from 10-second data, $C_{HR}/C_{10s} = 0.7$.

[3] Predicted by Dow for worst-case conditions using the Gaussian plume model. Data presented as testimony during State of California multi-agency hearings, December, 1976.

[4] NO_2 concentrations predicted using the experimental σ_y and σ_z values and projected Dow emissions in the Gaussian plume model. Although σ_y and σ_z were obtained from 10-second average tracer data, comparison of 10-second and hourly averaged tracer data indicate that $C_{HR}/C_{10s} = 0.7$. The values given above have been converted to hourly averaged levels.

(California air quality standard for NO_2 equals 250 ppb, hourly average)

9. Maximum concentrations of NO_2 (measured at the Montezuma Hills by Rockwell and at Stockton by the San Joaquin APCD) were found to be about 0.06 ppm. During Sea Breeze conditions, NO_2 concentrations from the projected Dow emissions were estimated to be greater than 0.06 ppm up to about 4 km downwind. During Sea Breeze Tail conditions, NO_2 concentrations from the projected Dow emissions were estimated to be greater than 0.06 ppm up to about 24 km downwind. During Nighttime conditions, NO_2 concentrations from the projected Dow emissions were estimated to be greater than 0.06 ppm up to about 14 km downwind. The emission rate of NO_2 from the Dow site was taken to be 9.4 tons/day; NO was assumed to be converted rapidly to NO_2 (Figure 35).

10. A reasonable correlation was found to exist between the horizontal standard deviation of the wind, σ_θ, and the horizontal dispersion parameter of the plume, σ_y. This correlation, $\sigma_y = 0.8 x \sigma_\theta$, can be used in estimating the dispersion of plumes emitted from the Dow site during times other than those of the test period (Figure 36).

11. Forward air parcel surface trajectories, based upon numerical solutions to the two-dimensional mass balance equation (Goodin, 1977) are in excellent agreement with the tracer transport path and transport time observed in Test 1. The trajectories were constructed from a series of hourly wind vector fields which, in turn, were numerically determined from the surface and upper air wind data. A typical surface wind vector field from Test 1 is shown in Figure 37.

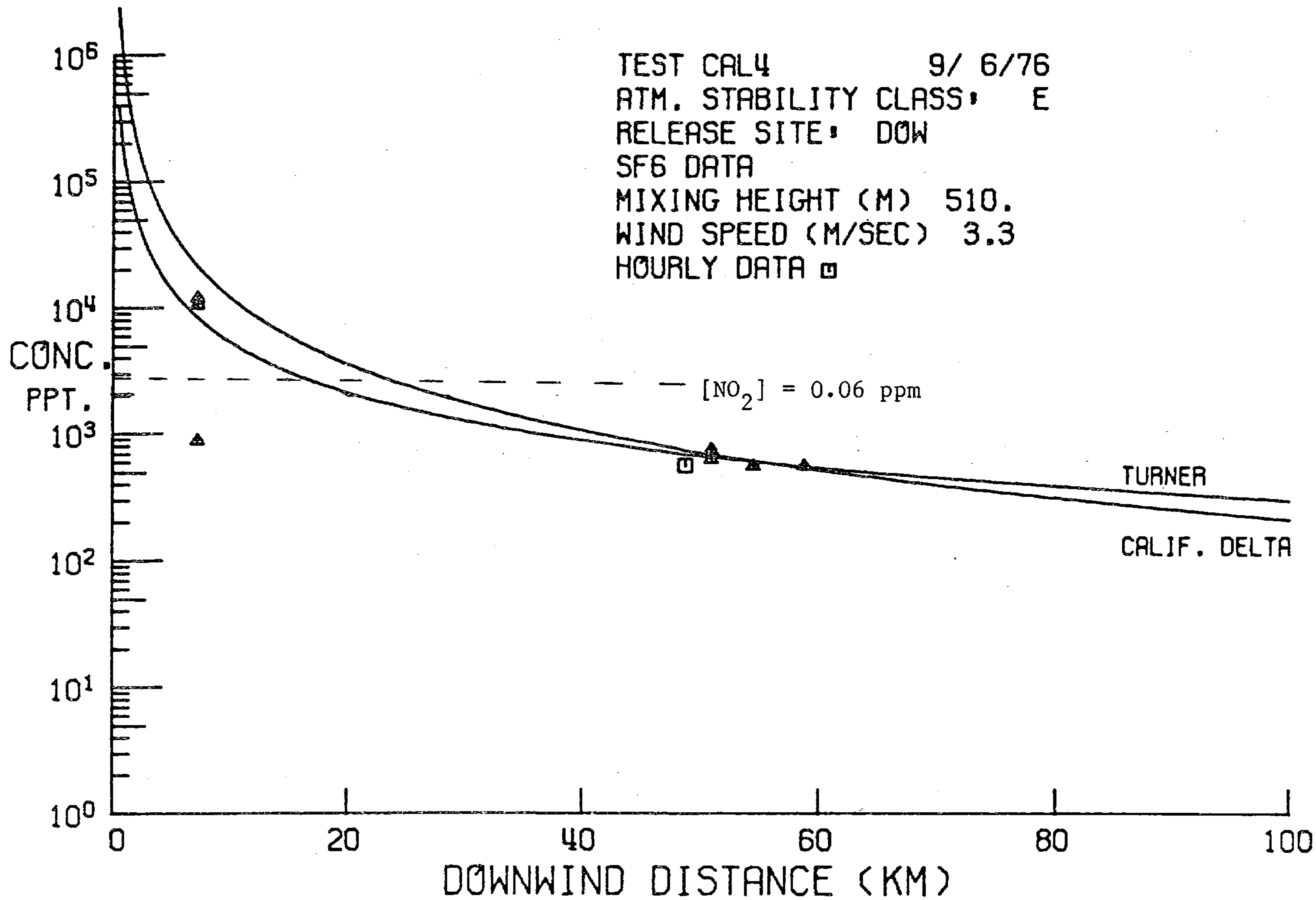


Figure 35. Estimation of distance downwind of the Montezuma Hills where the concentration of NO_2 (caused by projected Dow NO emissions) equals maximum ambient levels (NO is assumed to be rapidly converted to NO_2).

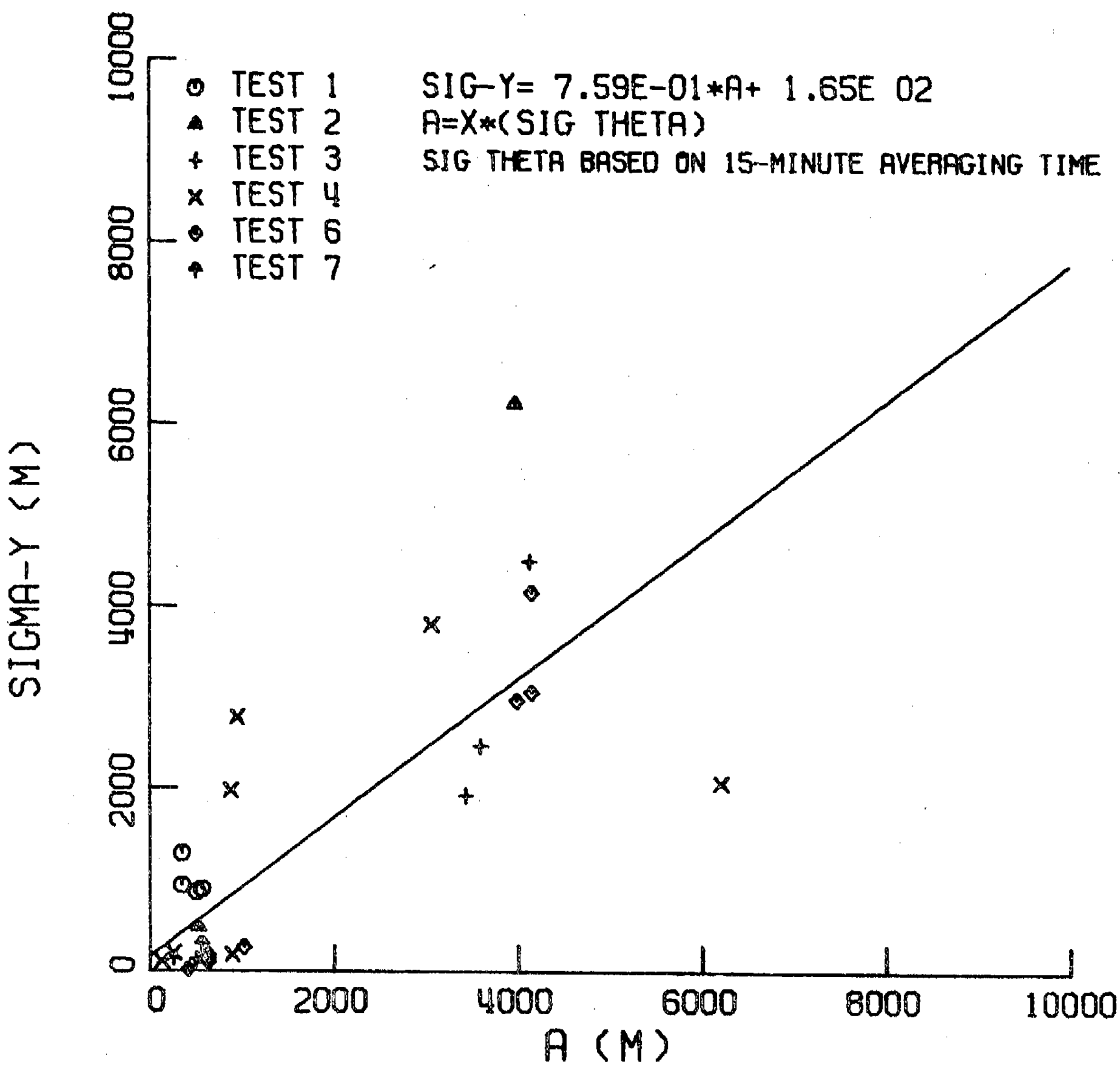


Figure 36. Horizontal crosswind dispersion parameter, σ_y, as a function of the horizontal standard deviation of the winds, σ_θ, measured at the Montezuma Hills.

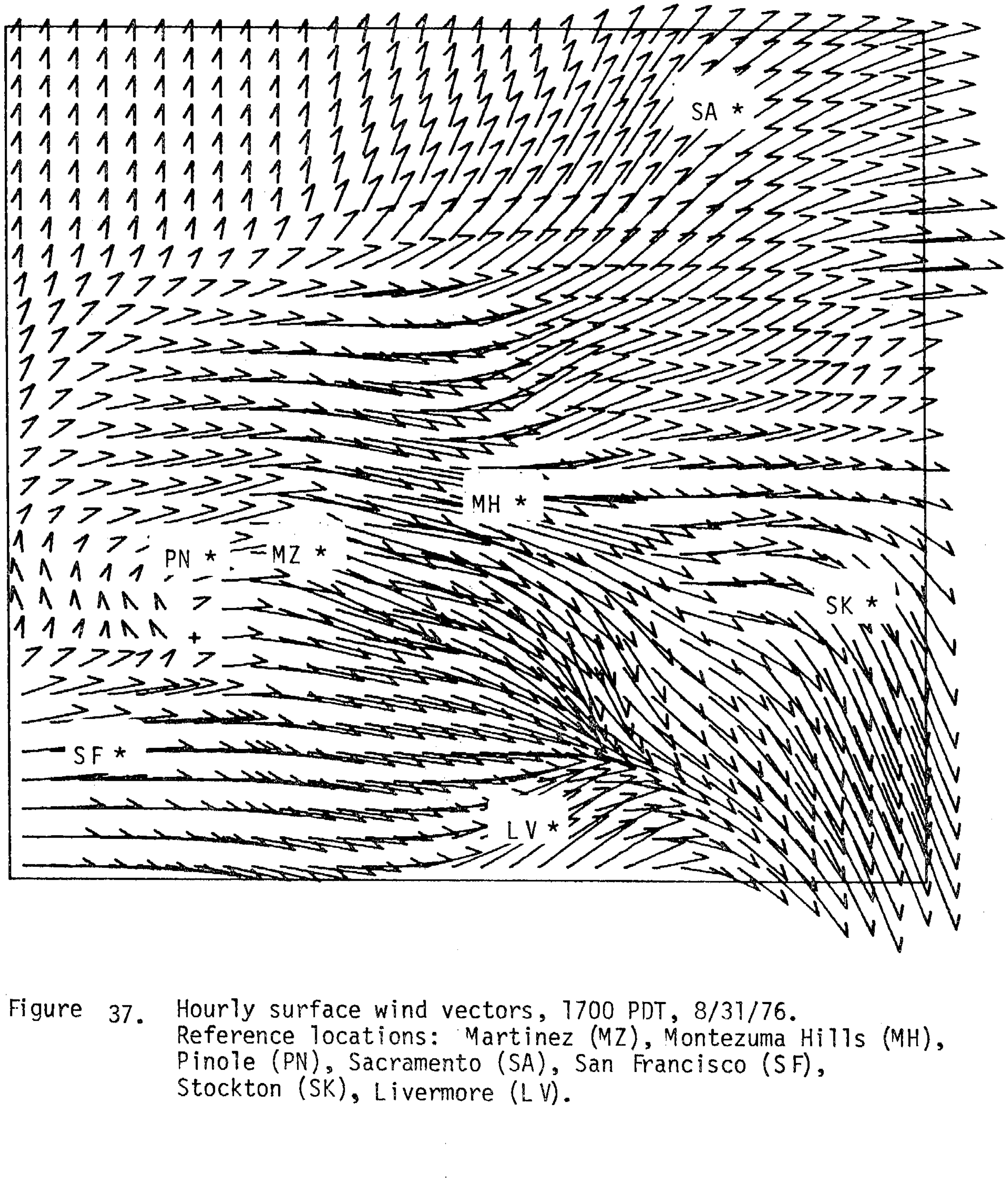


Figure 37. Hourly surface wind vectors, 1700 PDT, 8/31/76.
Reference locations: Martinez (MZ), Montezuma Hills (MH), Pinole (PN), Sacramento (SA), San Francisco (SF), Stockton (SK), Livermore (LV).

The effects of the terrain upon surface wind flow are readily apparent when the surface pattern in Figure 37 is compared to the upper air pattern (averaged from 300 to 900 feet) shown in Figure 38. Above the surface, winds are relatively uniform from the west throughout the Delta region. The trajectories beginning at each hour of the tracer release from the Montezuma Hills are presented in Figure 39. The experimental and calculated trajectories both crossed Highway 99 near Tracy and reached that area around 1700 PDT.

12. The results of the wind field calculations, the applicability of the Gaussian plume model in the region, and the observed relationship between σ_y and σ_θ provide a means for extending the results of this tracer investigation to other periods of the year. The preliminary success of the numerical trajectory analysis indicates that pollutant trajectories during other periods of the year can be constructed from a suitable collection of wind data. The majority of the surface stations used in this report record data on a year-round basis. By measuring the standard deviations of the wind, σ_θ, at an emission point, values of σ_y can be determined for various downwind distances. These values can be used in the Gaussian plume model to yield reasonable estimates of pollutant dispersion. The surface trajectory analysis will give an indication of the transport path.

13. The tracer data indicate that the proper positioning of an air quality monitoring station along Highway 160 will be extremely sensitive to the position of proposed emission sources within the Montezuma Hills. In order to properly monitor the area close

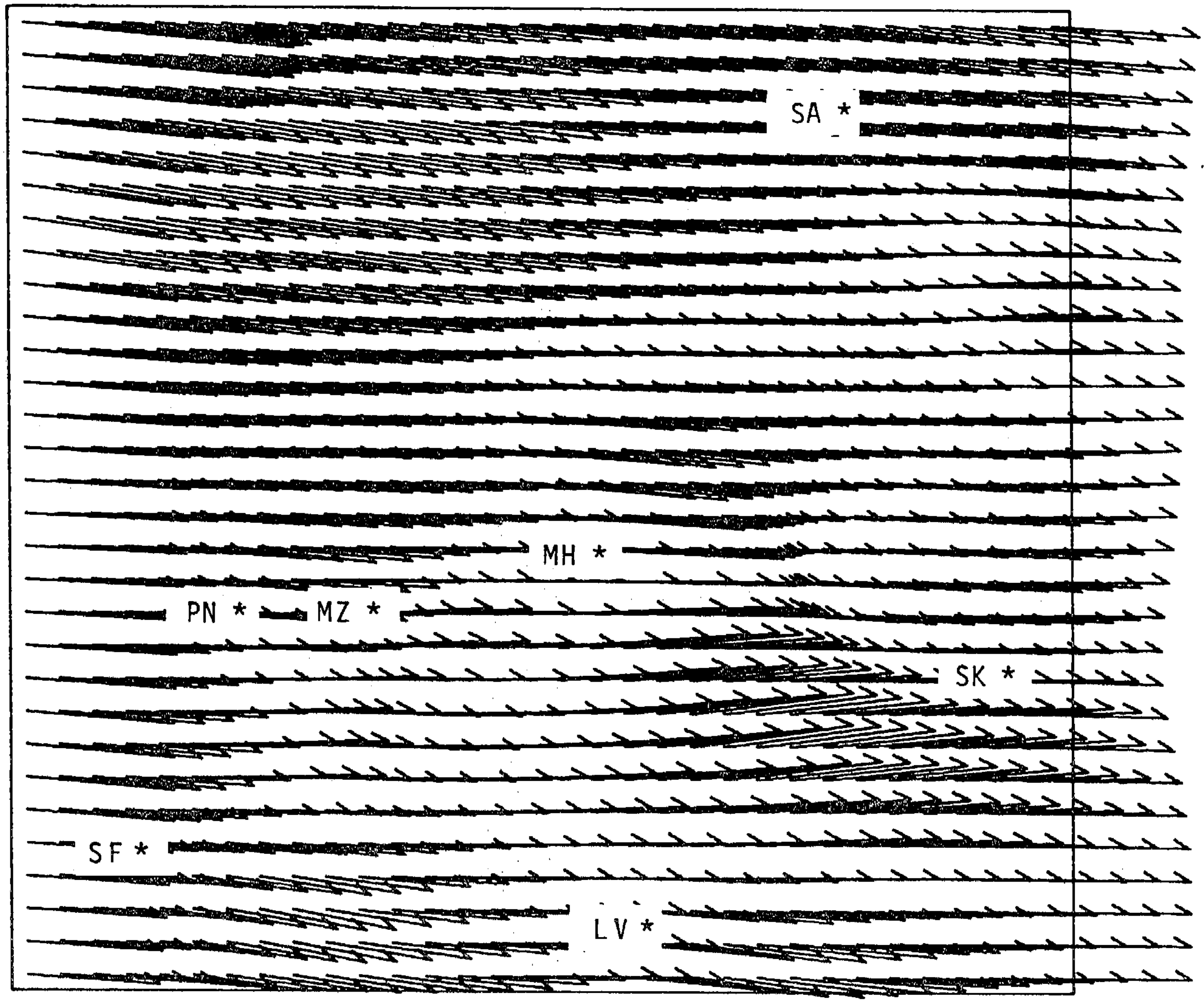


Figure 38. Hourly upper air wind vectors; average wind field from 300 to 900 feet, 1700 PDT, 8/31/76.
Reference locations: Martinez (MZ), Montezuma Hills (MH), Pinole (PN), Sacramento (SA), San Francisco (SF), Stockton (SK), Livermore (LV).

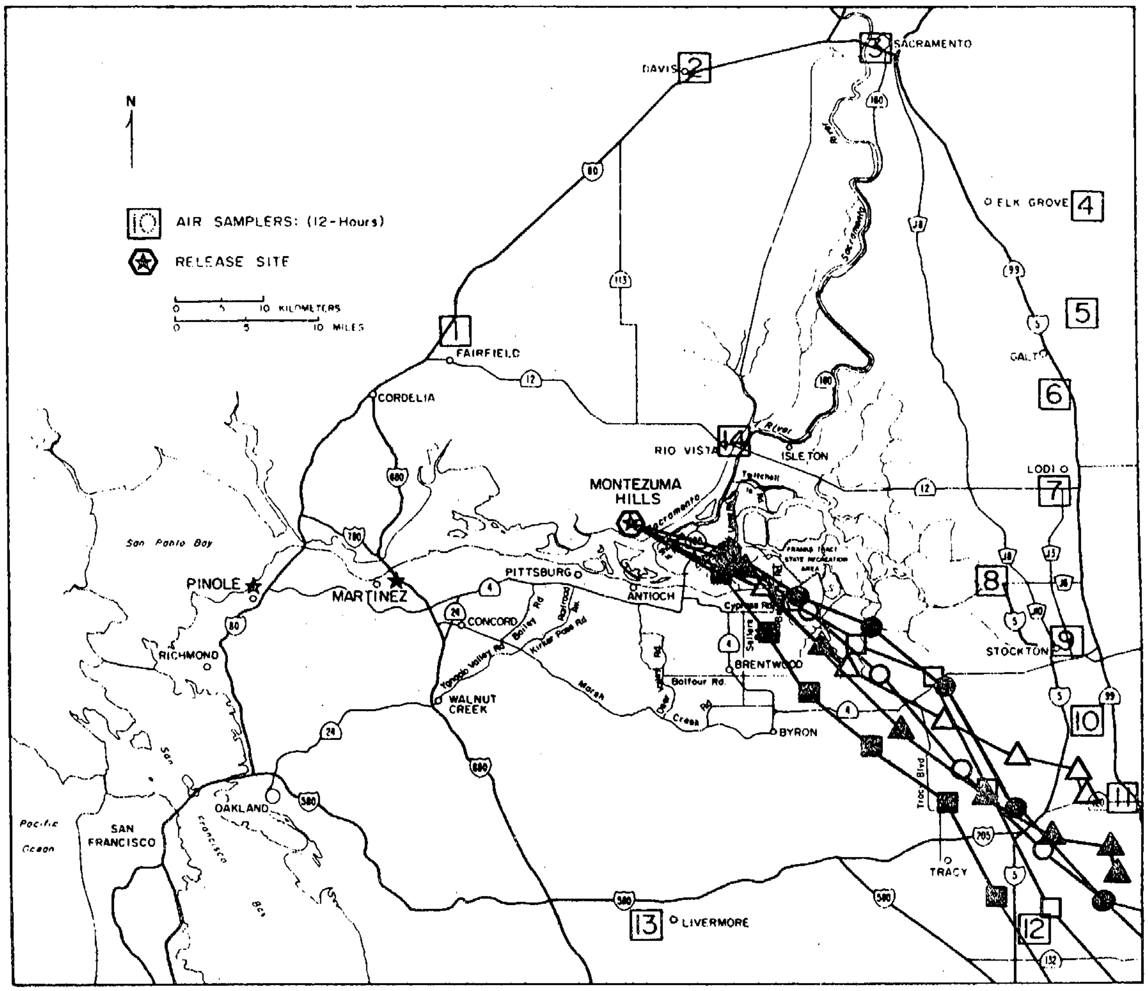


Figure 39. Forward air parcel surface trajectories; each point represents one hour of transport, 8/31/76. Trajectories were started from the Dow site in the Montezuma Hills at the following times:

1200 PDT ■

1300 PDT □

1400 PDT ●

1500 PDT ○

1600 PDT ▲

1700 PDT △

to the proposed industrial sites, it may be necessary to utilize a mobile monitoring system or a series of fixed monitoring sites. Further downwind, additional monitoring sites between Lodi and Tracy may be considered useful. It is apparent that during periods of marine flow at least a portion of Bay Area pollutants as well as pollutants from the Delta region are transported into the Stockton area. It appears that further study concerning the chemistry, transport, and dispersion of pollutants entering the San Joaquin Valley will be of considerable interest.

APPENDIX A

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